4 HABITAT CONDITIONS AFFECTING LAKE OZETTE SOCKEYE

This chapter contains a summary of sockeye salmon habitat conditions within the Lake Ozette watershed, focusing on estuary and near-shore, Lake Ozette, the Ozette River, and the Lake Ozette tributaries. While most of the information presented here was compiled from past reports and studies, a considerable amount of it also comes from firsthand fieldwork in the watershed by the contributing authors. Throughout development of this report, the authors and contributors spent numerous days in the field to “ground truth” and document habitat conditions. These new findings are included in the following discussion.

4.1 ESTUARY AND NEAR-SHORE

The Ozette River estuary is small relative to the estuaries of other similar sized, nearby river systems (e.g. Sooes River). Currently, a spit composed primarily of gravel and cobble constricts the mouth, forcing the river’s outlet to the south side of the narrow valley. The Ozette River estuary extends upstream from the spit for approximately 4,300 to 4,600 feet (1,300-1,400 m) to where a steep riffle serves as the divide between the estuarine and riverine environments. The tidally influenced section of the Ozette River is deep, averaging about 3 meters, with depths of over 5 meters in some locations.

Little documentation of current and/or historical estuary conditions exists. However, a cursory review of historical aerial photos reveals that the mouth of the Ozette River has changed noticeably since the 1950s. Aerial photos from the 1957 flight depict greater tidal energy entering the river system than under current conditions. The spit that currently exists along the tidal interface of the river did not exist in 1957, although a submerged island can be observed at the mouth of the river. By 1971, a spit has developed; in aerial photos the spit appears un-vegetated and more transitory in nature than in the present day (Figure 4.1). In photos from 1997, the top of the bar is vegetated and appears to have stable driftwood accumulation (Figure 4.1; Smith 2000). In field visits during the summer of 2000, healthy stands of beach rye, stable accumulations of LWD, and young conifer trees were present on the surface of the spit.

The conditions and processes that formed and maintain the channel depths observed in the lower river are not well understood. Photo evidence from 1953-2003 (Figure 4.1 supports the idea that tidal flux and storm surge energies expressed upon the estuarine channel may have been greater in the past, if the bar at the mouth represents a recent phenomenon. There has been speculation that the bar formed after wood removal in 1952, and has reduced tidal flux (Smith 2000). While it is possible that wood removal in 1952 and/or cedar logging/salvaging in the lower river in the 1920s (see Section 1.5.5) caused changes in water surface elevation at the mouth, timing and magnitude of low discharge, or estuary sediment dynamics, the relationship between current estuary conditions and past conditions remains unclear.

Nearshore physical habitat in the vicinity of the Ozette River is characterized by a gently sloping marine shore platform with abundant boulders and outcrops of resistant rock. To the north of the estuary, this platform is bounded on the shore by a long (~3.1 mi, 5 km) sand, gravel, and cobble beach backed by an eroding bluff. To the south of the river, at Cape Alava, about 1.5 miles distant, the shore platform slope decreases, and widens considerably after a series of closely spaced rocky headlands separated by short sand and gravel beaches. The seaward boundary of the shore platform can be roughly demarcated by sea stacks, which dot the coastline in the vicinity. The remote and relatively pristine nature of the shoreline in the vicinity of the Ozette River is reflected in the diversity and abundance of marine life in the area. Pinnipeds are seasonally abundant (See Sections 5.2.2.1.1 and 5.2.2.1.2) and number in the thousands within a few miles of the mouth of the Ozette River (Gearin et al. 1998). Nearshore habitat complexity is high, and both predator and prey species are believed to be abundant.

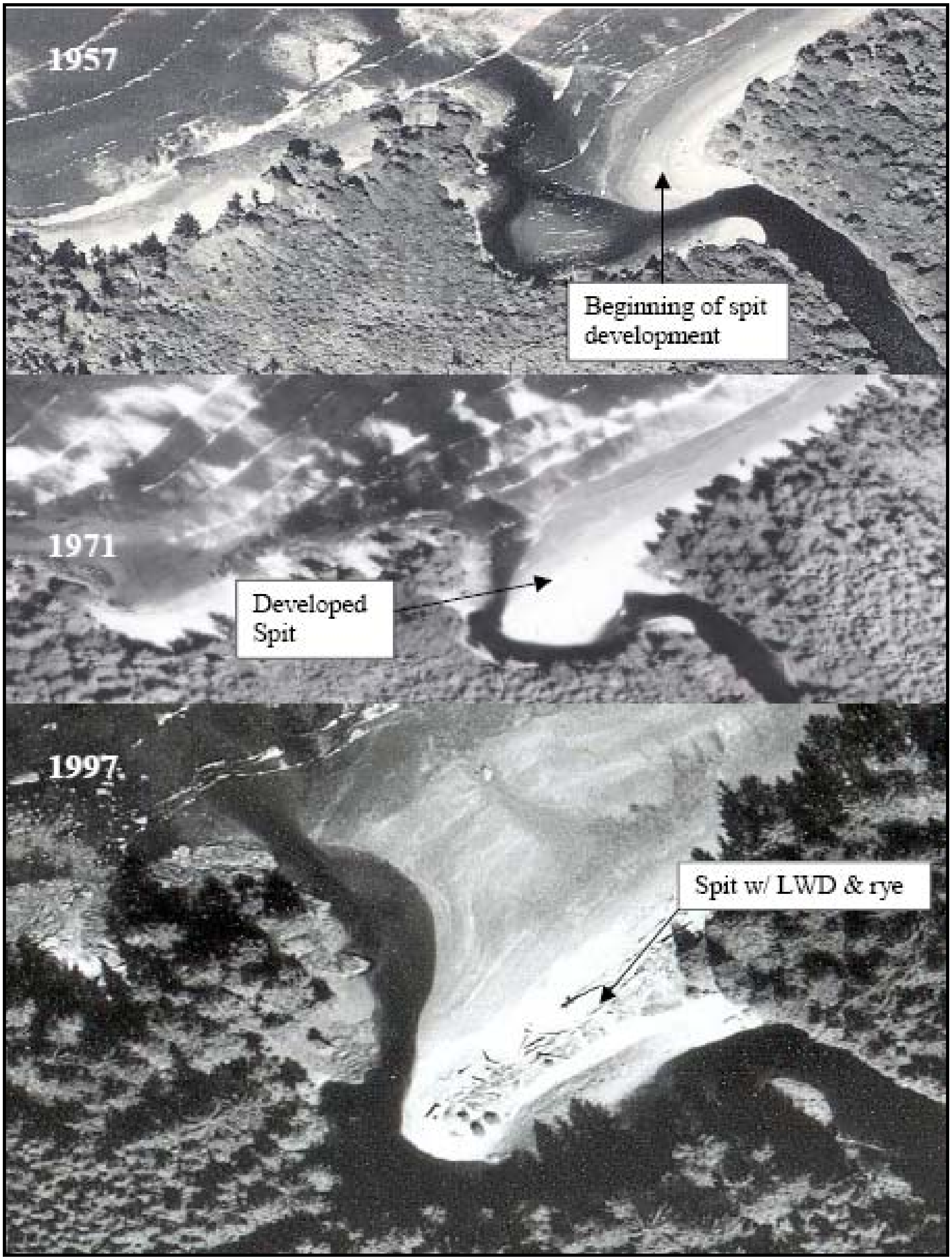

Figure 4.1. Ozette River spit evolution from 1957 to 1997 (source: Smith 2000).

4.2 LAKE OZETTE

4.2.1 Shoreline and Beach Conditions

Lake Ozette's shoreline is 36.5 miles (57 km) long (Ritchie 2005). Shoreline vegetation, substrate, and topography vary widely around the lake, with additional variations according to time of year and lake level. Where the beaches and shorelines are very gently sloping, lake level may fluctuate by as much as 8 to 12 feet (2.4 to 3.6 meters) between summer low and winter high.

Lake Ozette shoreline conditions were first described by Bortleson and Dion (1979), based upon shore surveys conducted in August 1976. They observed beach and lakebed substrates that were most commonly a mixture of silt, sand, gravel, and cobbles. Bortleson and Dion (1979) also observed that much of the beach was exposed during the summer months, allowing for the growth of grasses, shrubs, and other vegetation. Meyer and Brenkman (2001) conducted surveys of the lakeshore during the summer of 1994 and determined that much of the shoreline substrate was composed of fine sediment. Coarser sediment including gravel and cobble can be found at several locations around the lake (Figure 4.2).

Olsen's and Allen's beaches are a primary focus because they are the only two remaining beach spawning locations. Baby Island and Umbrella Beach are also of considerable interest because of historical observations of sockeye spawning at these locations. Factors that may affect beach and shoreline sediment conditions at both spawning beaches are not well understood, but include alterations of the lake's hydro-period, colonization of native and non-native vegetation, and reduced numbers of sockeye spawning on the beach. In the case of Olsen's Beach, potential additional factors include increased sediment delivery from nearby tributaries and shoreline development.

At mid- to upper elevations of both spawning beaches, sedges, sweet gale, and other vegetation occupy much of the beach area. Meyer and Brenkman (2001) noted that sweet gale, grasses, and sedges were observed at depths of up to 2m in December 1994, in the vicinity of where sockeye salmon were spawning. Seeps and springs have been mapped on both Olsen's and Allen's beaches, and appear to be areas where spawning activity is concentrated (see below). To date no comprehensive inventory of seeps and springs has been completed for Lake Ozette.

Olsen's Beach (see Figure 3.7 and Figure 3.8) extends from the southeast end of a shallow bay near the inlet of Elk Creek northwest for approximately 845 meters. Substrate along the southeast end of the beach is composed primarily of fine sand, silt, mud, and organic detritus. Substrate size grades into a matrix of coarse sand, pebbles, and gravel in a northwest direction; this is the core sockeye spawning site at Olsen's Beach (see Section 3.1.4). The core spawning area is focused around a small, approximately 6,400ft^2 (600m^2) spring. During winter 1999-2000, a thermograph deployed in the spring measured subsurface water temperature significantly warmer than ten other thermographs deployed at Olsen's and Allen's beaches (Figure 4.3).

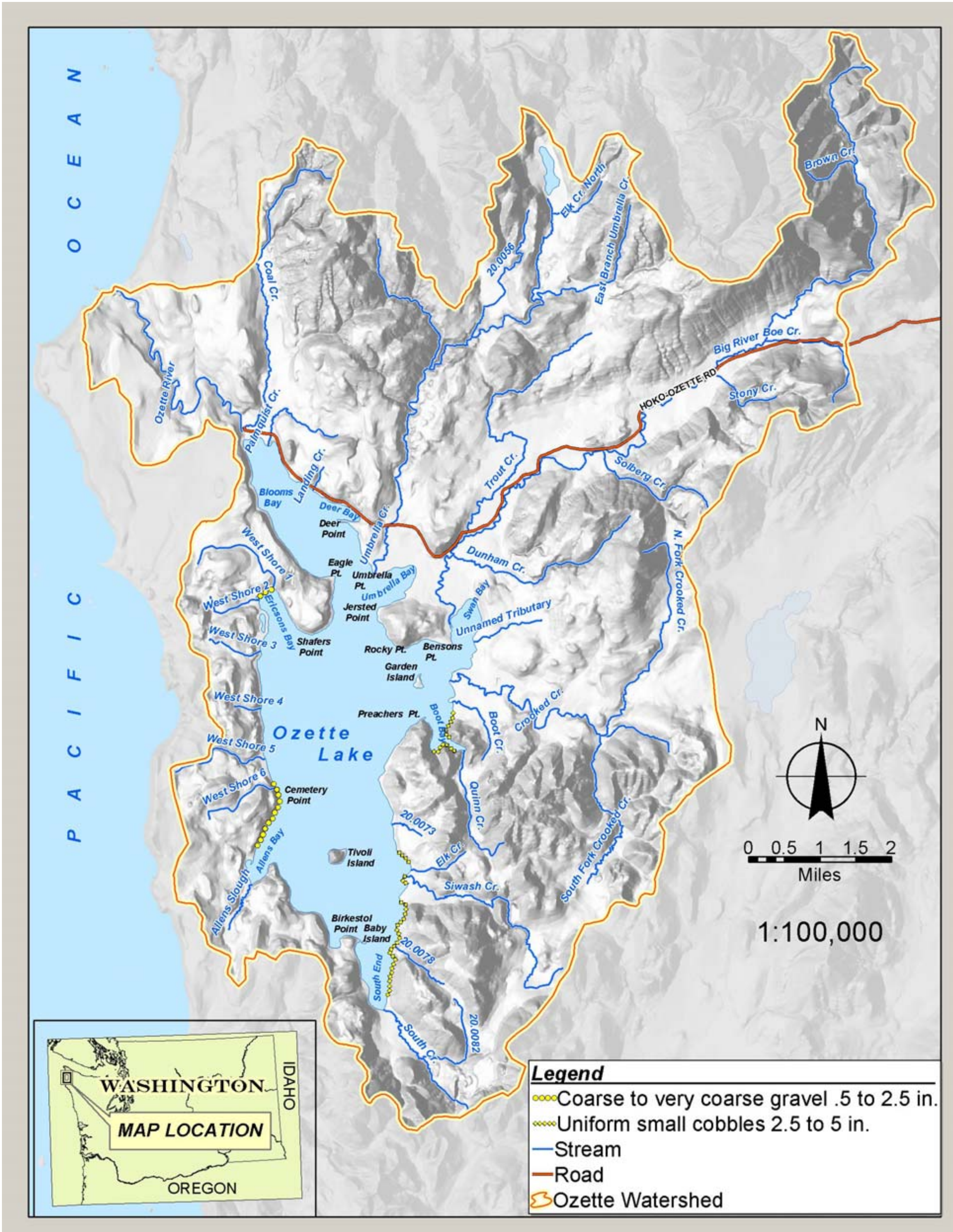

Figure 4.2. Generalized locations of beach substrate conditions suitable for sockeye salmon spawning (modified from Bortleson and Dion 1979).

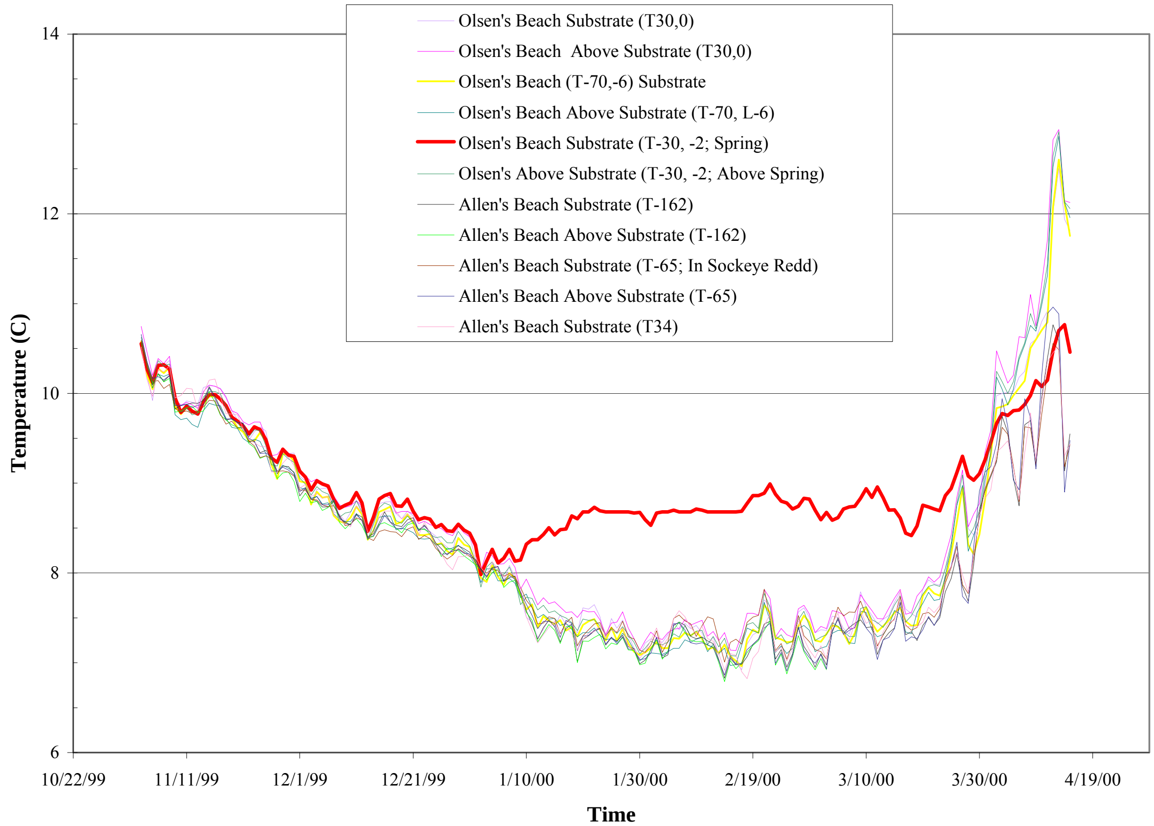

Figure 4.3. Comparison of water temperatures in substrate and directly above substrate at three sites on both Olsen's and Allen's beaches during the 1999/2000 sockeye spawning and incubation period (source: MFM, unpublished water temperature data).

Moving perpendicular to the beach along the primary spawning area, gravel quickly grades to sand (at a depth of about 3 m). Moving south from the primary spawning area, the slope of the bay floor is gentle, and substrate becomes fine and mucky, but to the north, the shoreline slope remains sandy and steeply sloping to an unknown depth (>5 m). Sockeye have been observed spawning in unusual depressions on these slopes at about 5 meters depth (MFM unpublished spawning ground survey data). Suitable substrate size extends along the shoreline northwest to an unnamed point where sockeye have been observed spawning in recent years. Gravel samples were collected along a 460-foot (140 m) transect that extended through the primary spawning area in 1999. A total of 13 samples were collected using a McNeil core sampler and processed using gravimetric sediment processing methods. It was found that levels of fine sediment within the spawning gravel ranged widely throughout the primary spawning area at Olsen's Beach. The percent "fines" (sediment particles less than 0.85 mm in diameter) ranged from 9.1% to 54.1%, averaging 25.2%. Additionally, 30 gravel samples were collected in September 2000, along the same transect as samples collected in 1999. Again highly variable percent fines were found in the spawning gravel samples. The percent fines ranged from 7.0% to 72.7%, averaging 27.0% (median=23.7%). Figure 4.4 depicts the results from spawning gravel samples and the sample proximity to sockeye spawning use categories for Olsen's Beach.

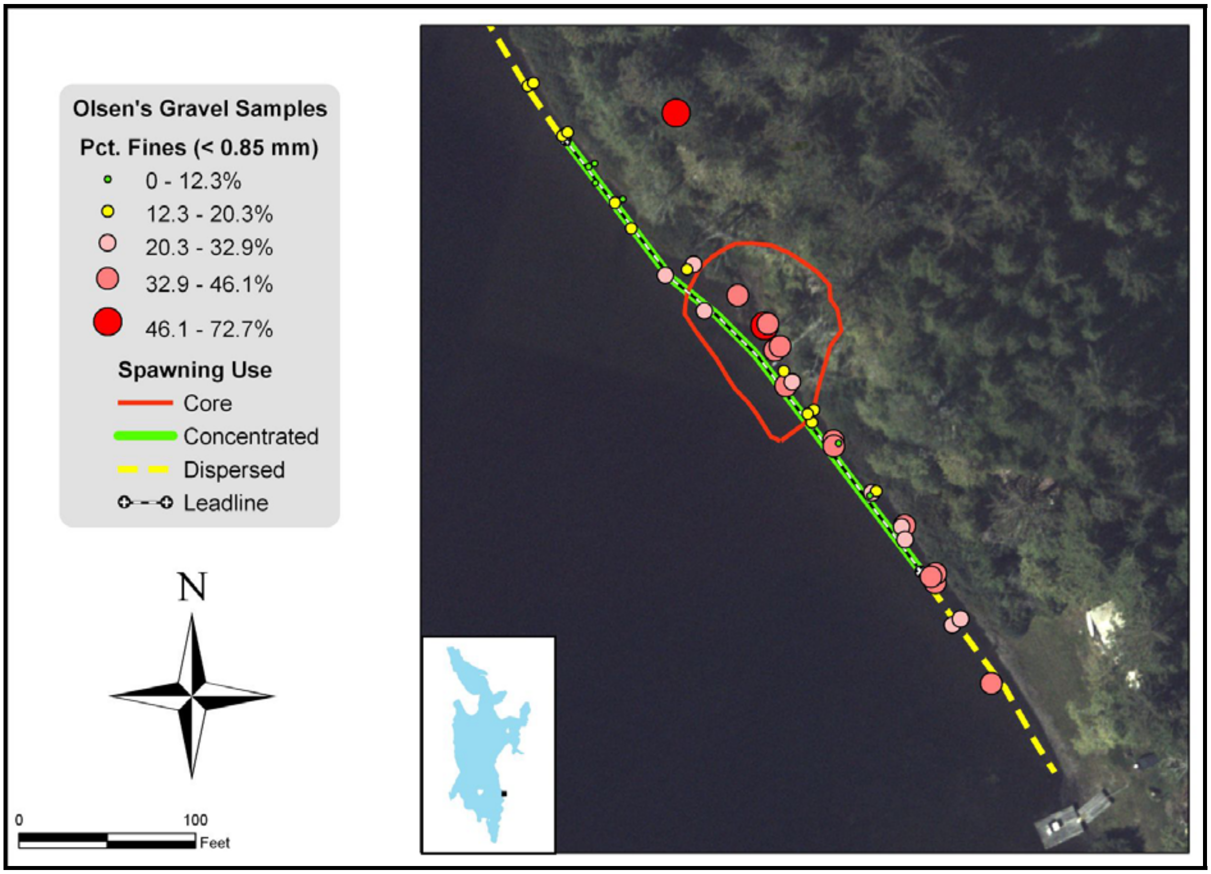

Figure 4.4. Olsen's Beach gravel sampling results for 1999 and 2000 and sample proximity to different categories of spawning use. (Note: The lead line corresponds to concentrated spawning use outside of the core use area.) (Source: MFM, unpublished data.)

The area previously described as Allen's Beach (e.g. MFM 2000) is generally a stretch of beach 100-200 meters (328-656 ft) north of Allen's Slough extending 200-300 meters (656-984 ft) northward. Spawning occurs along Allen's Beach (see Figure 3.7 and Figure 3.10) from the northwest end of Allen's Slough, north-northeast to Cemetery Point. Substrate along the southwest end of the beach is composed primarily of fine sand, silt, mud, and organic detritus. Substrate size quickly grades into a matrix of coarse sand, pebbles, and gravel in northwest direction. This area is sometimes referred to as South Allen's. Moving north-northeast from South Allen's Beach, substrate size generally increases, with cobbles becoming a dominant component near Cemetery Point. Moving in the offshore direction, the beach grades to sand and gently slopes to a depth of about 4 meters (13 ft) (relative to winter lake levels), where a distinct slope break occurs between about 4 and 6 meters (13 to 20 ft). Below about 6 meters (20 ft), the slope decreases again, and in some areas gravel can be found. Sockeye salmon have been observed spawning on this lower "shelf" at Allen's Beach to depths of approximately 10 meters (32 ft).

During the summer of 2005, lower and middle beach surfaces were classified into seven categories based upon dominant substrate types: cobble, cobble/gravel, cobble/fines, gravel/cobble, gravel, gravel/fines, and fines. A total of 1.6 miles (2.6 km) of shoreline substrate were mapped and classified (see Figure 3.10) from the south end of the spit in Allen's Bay to an unnamed tributary approximately 1 km northwest of Cemetery Point. Approximately 85% of the shoreline length contained substrate types used by spawning sockeye but only 26% of the shoreline was classified as containing concentrated spawning usage. Gravel was the dominant shoreline substrate (30%) by length followed by fines (14%) and cobbles (13%). The remainder of the shoreline length was a mixture of cobble, gravel, and fines (43%;Table 4.1).

Table 4.1. Allen's Beach area dominant substrate categories, number of segments, length of substrate categories, and percentage of beach length within specified length categories (source: MFM, unpublished shoreline survey data).

Dominant Substrate Category (lower and middle beach surfaces)	Number of Beach Segments	Total Length (Ft)	Total Length (m)	Percent of Beach within Specified Substrate Category
Cobble	2	1,096	334	12.6%
Cobble/Gravel	3	934	285	10.8%
Cobble/Fines	1	151	46	1.7%
Gravel/Cobble	2	2,194	669	25.3%
Gravel	4	2,604	794	30.0%
Gravel/Fines	2	439	134	5.1%
Fines	3	1,249	381	14.4%
Totals	**17**	**8,667**	**2,642**	**100.0%**

Mapping surveys conducted during the summer of 1999, when much of the beach was exposed during low lake level, identified numerous small seeps and springs in portions of the area used for spawning. A total of approximately 180 meters of beach were mapped during the summer of 1999. Attempts to measure thermal gradients around the springs during winter of 1999 and 2000 were unsuccessful (MFM unpublished data). Based upon the lack of thermal gradient around the seeps it was assumed that either: 1) the groundwater and lake water temperatures were the same, or 2) that the quantity of water emerging from the seeps was insufficient to be detected using the methods employed.

Utilization of Allen's Beach by spawning sockeye is less concentrated than Olsen's Beach. There is no core spawning area at Allen's Beach, unlike Olsen's Beach. MFM established a lead line transect for monitoring sockeye spawning along Allen's Beach in 1999 (along the mapped transect). This area (middle Allen's Beach) at the time was thought to have the highest density of spawners. Gravel samples were collected along a 170 meter (558 ft) transect that extended through the spawning area in 1999 (MFM unpublished data). It was later found that higher spawning density was actually to the south and another lead line transect was deployed in that area during the fall in 2000. A total of 11 gravel samples were collected using a McNeil core sampler and processed using gravimetric sediment processing methods. It was found that levels of fine sediment within the spawning gravel ranged widely along the transect. Percent fines (<0.85mm) ranged from 4.6% to 44.3%, averaging 24.6%. Figure 4.5 depicts location and percent fine sediment calculated for each of the 13 sediment samples collected in 1999.

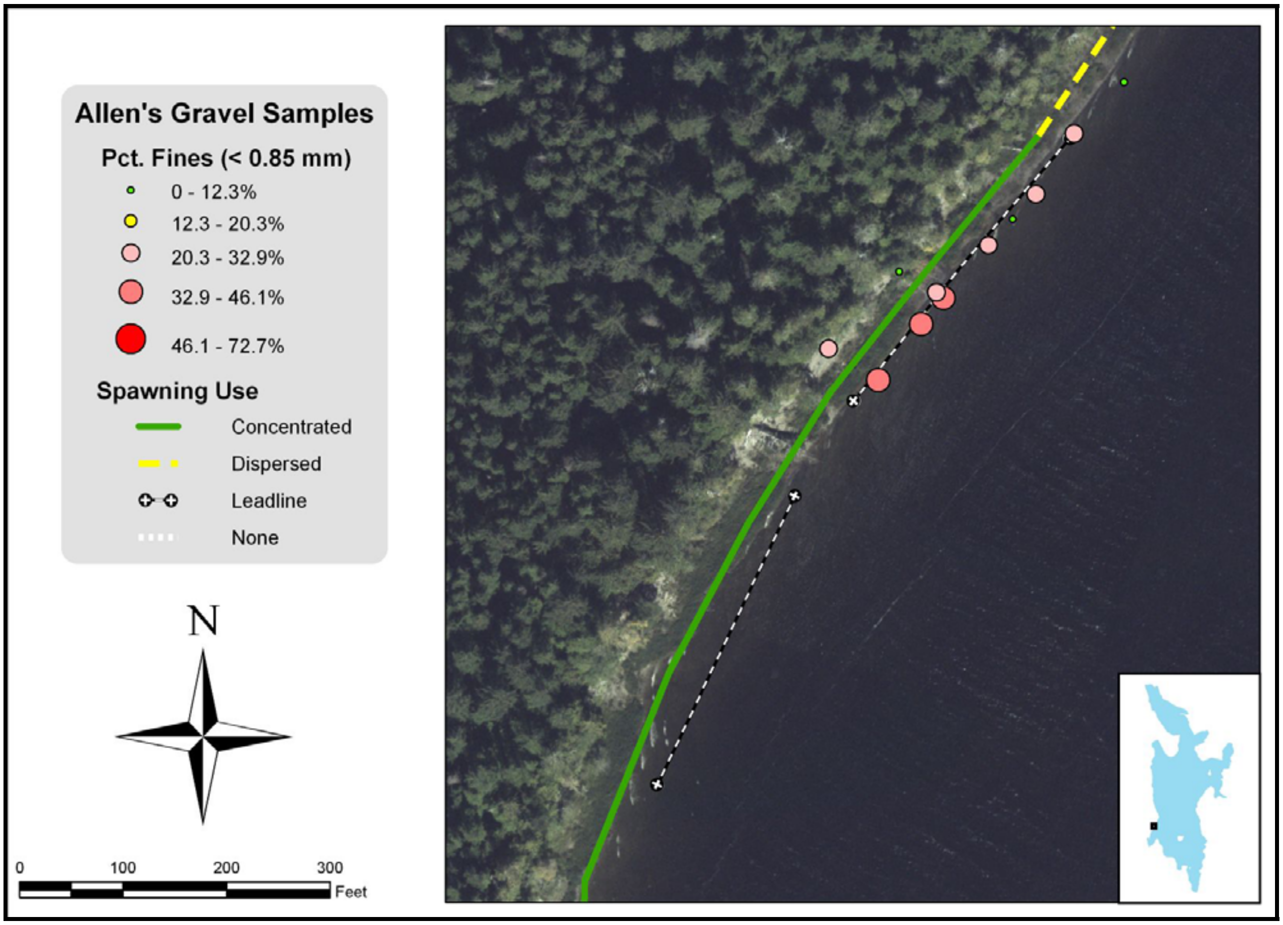

Figure 4.5. Allen's Beach gravel sampling results from 1999 and sample proximity to different categories of spawning use. (Note: There are two lead lines at Allen's Beach: Allen's and South Allen's. Note: Two gravel samples were located in the dispersed spawning use category.) (Source: MFM, unpublished shoreline survey data.)

There are additional differences between Olsen's and Allen's beaches. One factor that has been examined is difference in beach slope. The slope of Olsen's Beach where it is most heavily used by spawning sockeye is approximately 30% steeper than areas of concentrated spawning use at Allen's Beach. Beach slope at Olsen's Beach ranges from 10-12% gradient, whereas the slope at Allen's Beach ranges from 8% to 9% gradient. These differences may be a function of increased wave energy at Olsen's Beach. Figure 4.6 illustrates the differences in beach slope between Olsen's and Allen's beaches based upon typical cross-sections from the core and concentrated spawning areas.

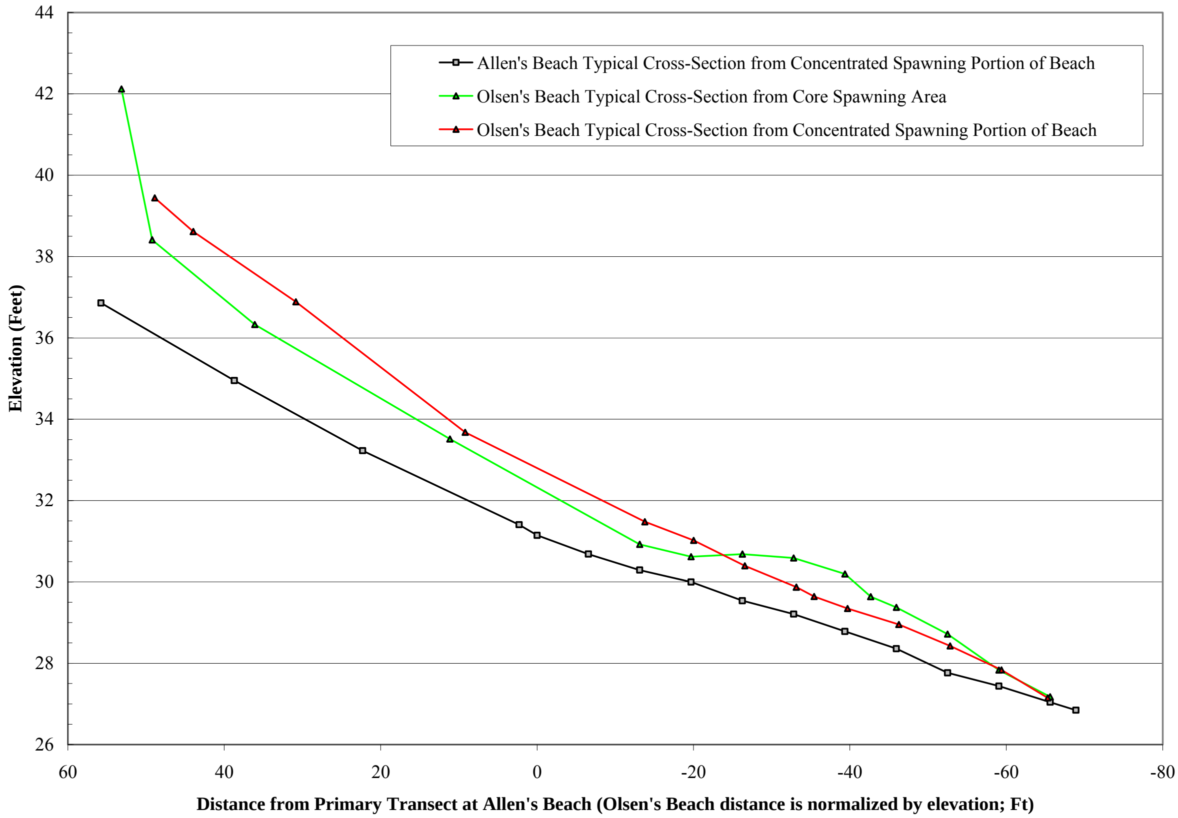

Figure 4.6. Comparison of beach slopes using typical cross-sections from Olsen's Beach core and concentrated spawning areas and Allen's Beach concentrated spawning use area. (Source: MFM, unpublished beach topography data.)

In addition to Olsen's and Allen's beaches, sockeye have been reported to spawn at Umbrella Beach, Ericson's Bay, and Baby Island, although a thorough review of Ozette literature, reports, and spawning ground survey data could not verify spawning in Ericson's Bay. Bortleson and Dion (1979) described the substrate in Ericson's Bay as suitable for sockeye spawning but did not document any spawning there. Meyer and Brenkman (2001) observed sockeye spawning at Baby Island during the winter of 1994. Field investigations and spawning ground surveys conducted by MFM and ONP during the winters of 1999 and 2000 revealed that very little spawning gravel is present along the shores of Baby Island. Besides Olsen's and Allen's beaches, Umbrella Beach has the best-documented account of beach spawning sockeye. Shoreline and delta conditions are significantly different now from what they were in 1964 (Figure 4.7). Herrera (2006) estimated that delta growth between 1964 and 2003 was approximately 5.7 acres (23,000 m^2). Much of the delta growth described by Herrera (2006) was just north of the mouth of Umbrella Creek. This is the area where spawning sockeye salmon were observed by Dlugokenski et al. (1981). Much of the new (post-1964) delta is now vegetated in shrubs, as is much of the older (pre-1964) delta, which contained little vegetation along the lake margins in 1964.

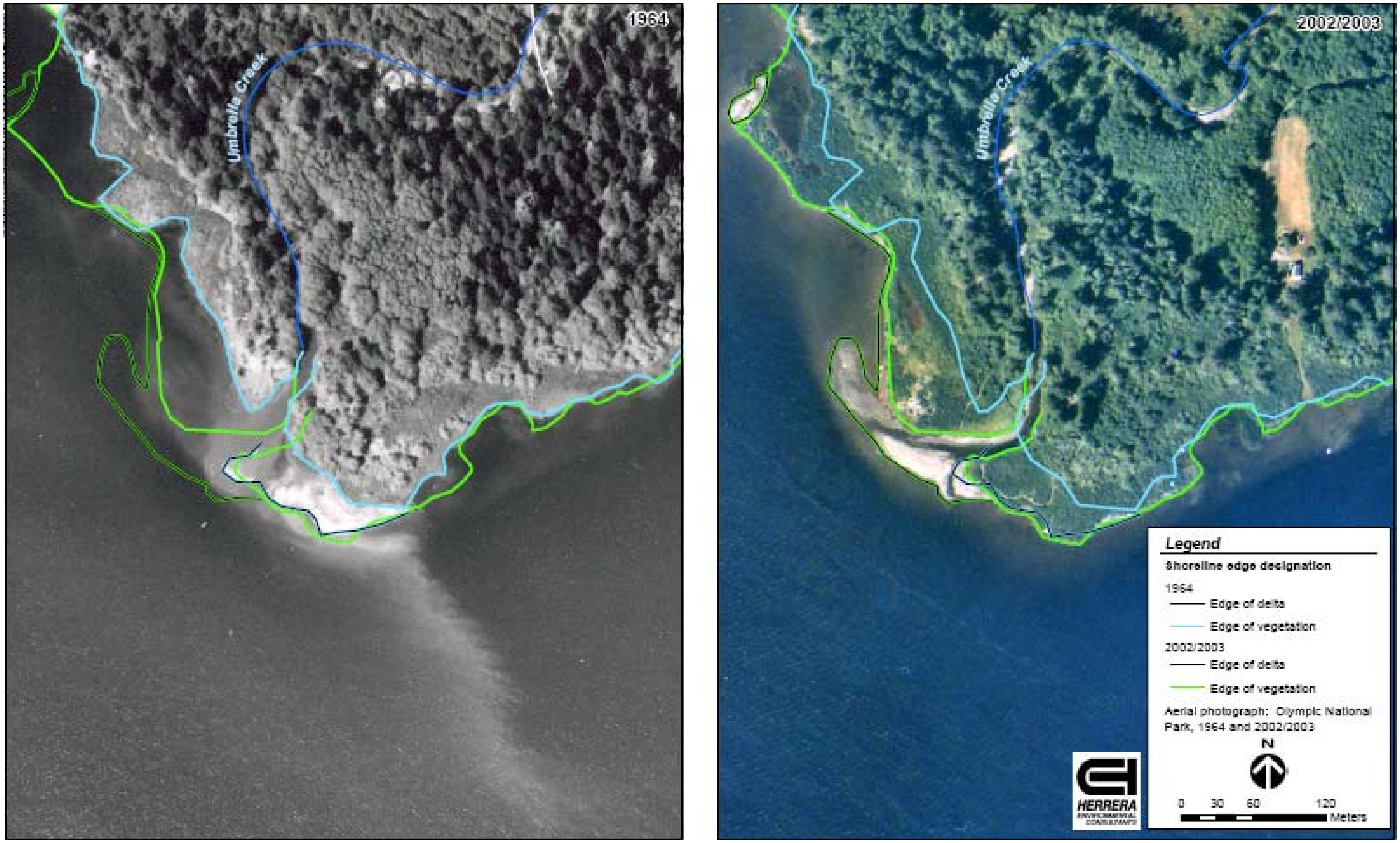

Figure 4.7. Comparison of 1964 and 2002 shoreline and delta conditions at the mouth of Umbrella Creek (source: Herrera 2005)

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A preliminary comparison of shoreline vegetation and sediment dynamics based on aerial photography in 1953 and 2003 (Ritchie 2005) found that significant increases in vegetation cover along the Ozette shoreline likely occurred in the last 50 years. About 28.3 miles (45.6 km) of shoreline were analyzed for vegetation changes between 1953 and 2003, and classified linearly as increase, decrease, or no change. Of this length, about 11.4 miles (18.4 km) showed an increase in vegetation cover, 0.1 miles (0.16 km) showed a decrease, and 16.8 miles (27.0 km) showed no change. Much of the shoreline classified as unchanged was completely vegetated prior to 1953. Changes were particularly noticeable along the north end of the lake and near the mouth of Umbrella Creek.

Ritchie (2005) detected increases in vegetation colonization along a fraction of the shoreline lengths at both Allen's and Olsen's beaches. Vegetation colonization at Allen's Beach was primarily to the south of the zone categorized as concentrated spawning use and to the north near Cemetery Point. At Olsen's Beach, vegetation encroachment was limited to areas just south of the northern concentrated spawning area and a zone 100 meters (328 ft) north of the core spawning area. Ritchie (2006) completed a second, higher resolution analysis motivated by results of the preliminary comparison. The second analysis delineated patches of unvegetated shoreline that could be resolved in photos from 1953 to 2003 at a scale of 1:300 or better, for the entire length of shoreline visible in 1953 and 2003 photos.

Ritchie's second analysis (2006) also found that the area of unvegetated shoreline decreased from 1953 to 2003. Ritchie identified 1,034,887 ft^2 (96,144 m^2) of unvegetated shoreline around the lake in 1953, and only 451,561 ft^2 (41,951 m^2) of unvegetated shoreline in 2003, a decrease of 56%. Ritchie found that unvegetated area at Allen's Beach dropped by 67%, from 125,645 ft^2 (11,673 m^2) in 1953, to 41,716ft^2 (3,876 m^2) in 2003 (Figure 4.8). The length of shoreline analyzed was 8,670 ft (2,643 m). Unvegetated area at Olsen's Beach declined from 27,322 ft^2 (2,538 m^2) in 1953, to 9,343 ft^2 (868 m^2) in 2003, a decrease of 66% over 2,804 ft (855 m) of shoreline assessed (Figure 4.9).

Many protected embayments were fully vegetated in the 1953 photos and remained so in 2003. Negligible change occurred in Deer Bay, Swan Bay, Allen's Slough, and the South End. The greatest decreases in unvegetated shoreline occurred on the east side of the North End north of Blooms Bay, at Shafer's point, at and near Cemetery Point, on the east shore opposite Cemetery Point, and between Jersted Point and Benson's Point (Figure 4.10). A region with a notable increase in unvegetated shoreline was identified at the Umbrella Creek delta, where Herrera (2006) estimated that delta growth between 1964 and 2002 was approximately 5.7 acres (23,000 m^2). However, virtually all of the area of unvegetated beach in 1953 was covered with vegetation in 2003. The current unvegetated shoreline at this locale consists entirely of sediment delivered to the lake from Umbrella Creek since 1953. A second area with a small increase in unvegetated shoreline was identified at the delta of a small, steep tributary (20.0078) east of Baby Island.

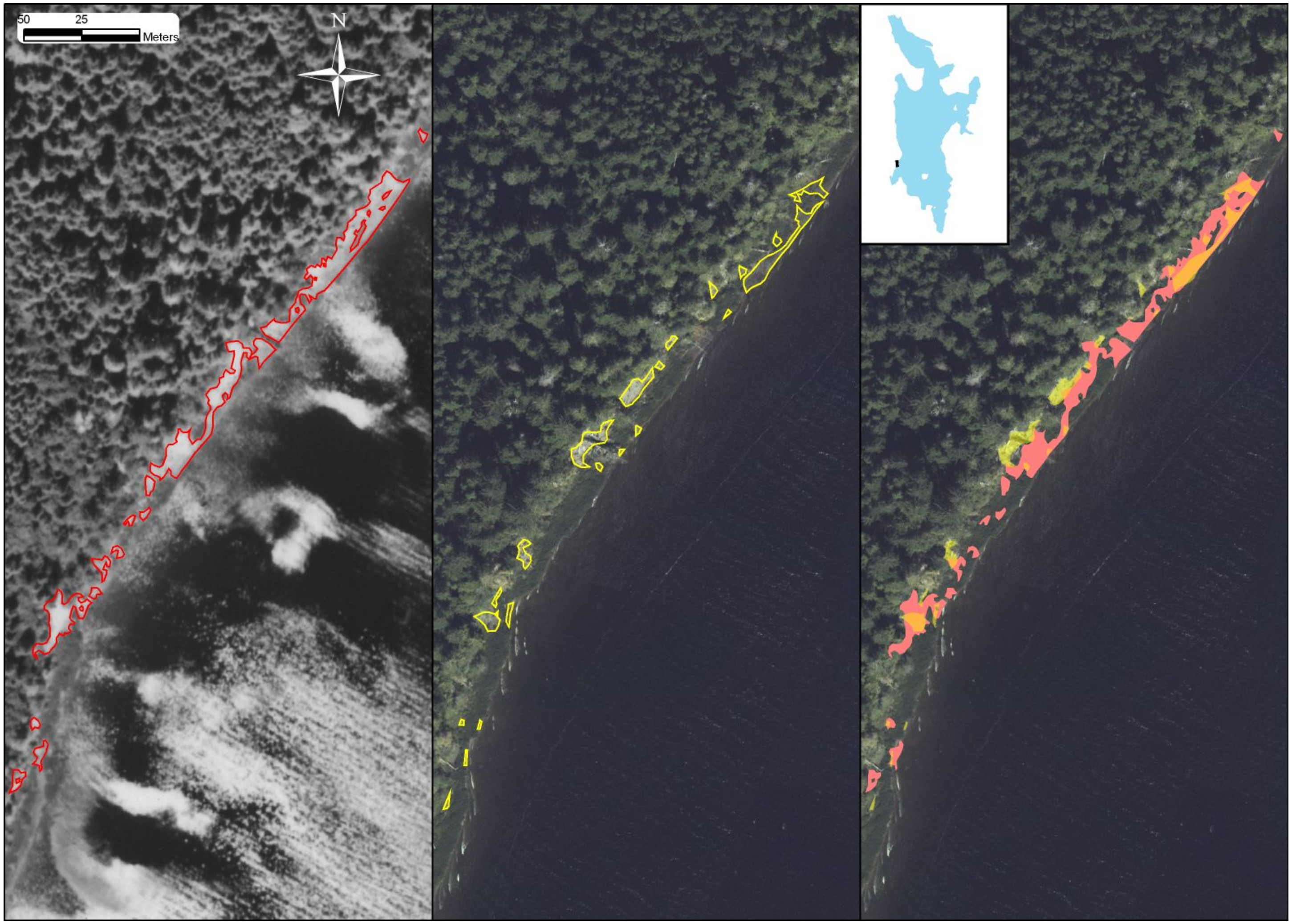

Figure 4.8. Comparison of a portion of Allen's Beach from 1953 to 2003. Red polygons delineate unvegetated shoreline in 1953 (left image) and yellow polygons delineate unvegetated area in 2003 (middle and right images).

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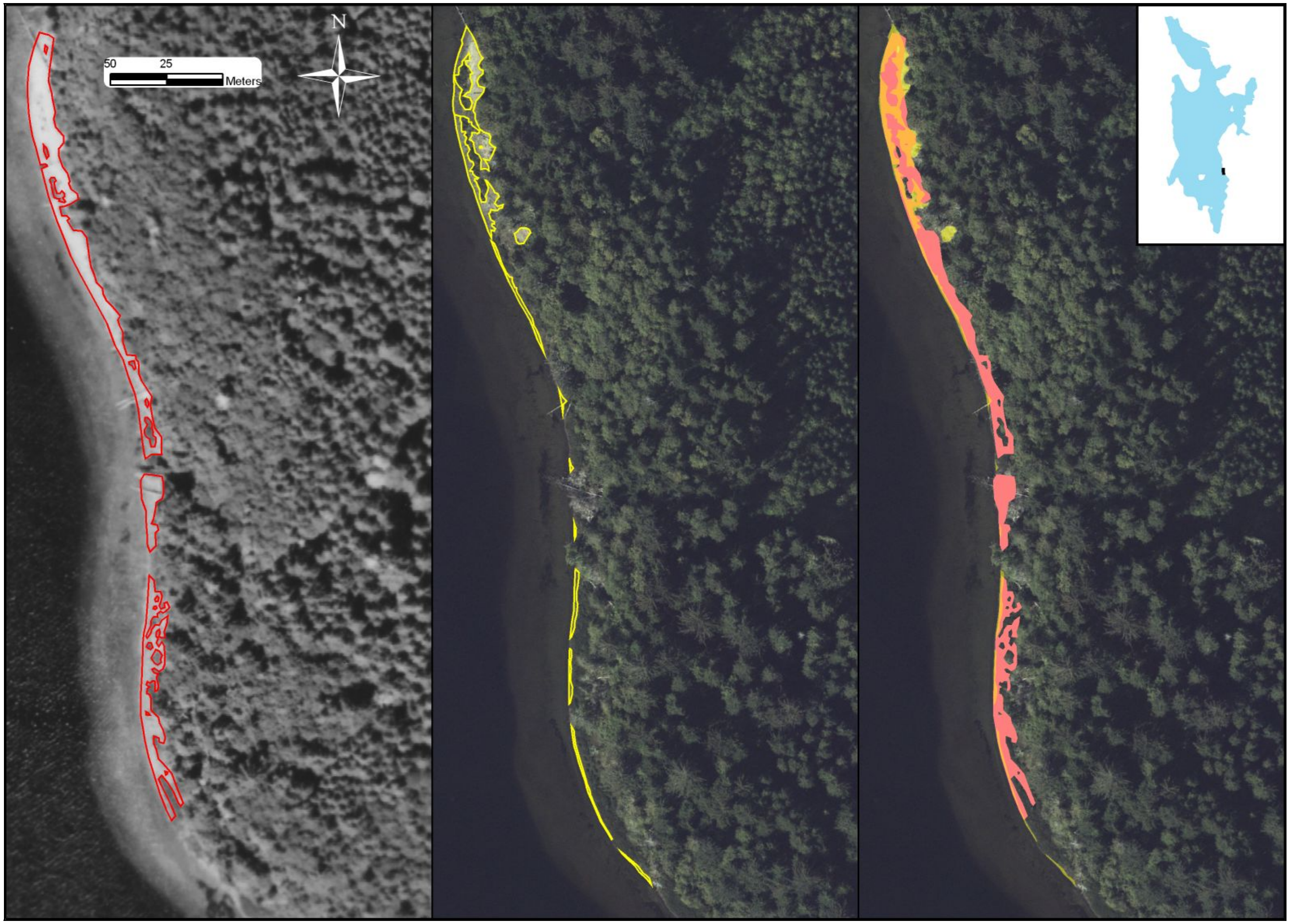

Figure 4.9. Comparison of a portion of Olsen's Beach from 1953 to 2003. Red polygons delineate unvegetated shoreline in 1953 (left image) and yellow polygons delineate unvegetated area in 2003 (middle and right images).

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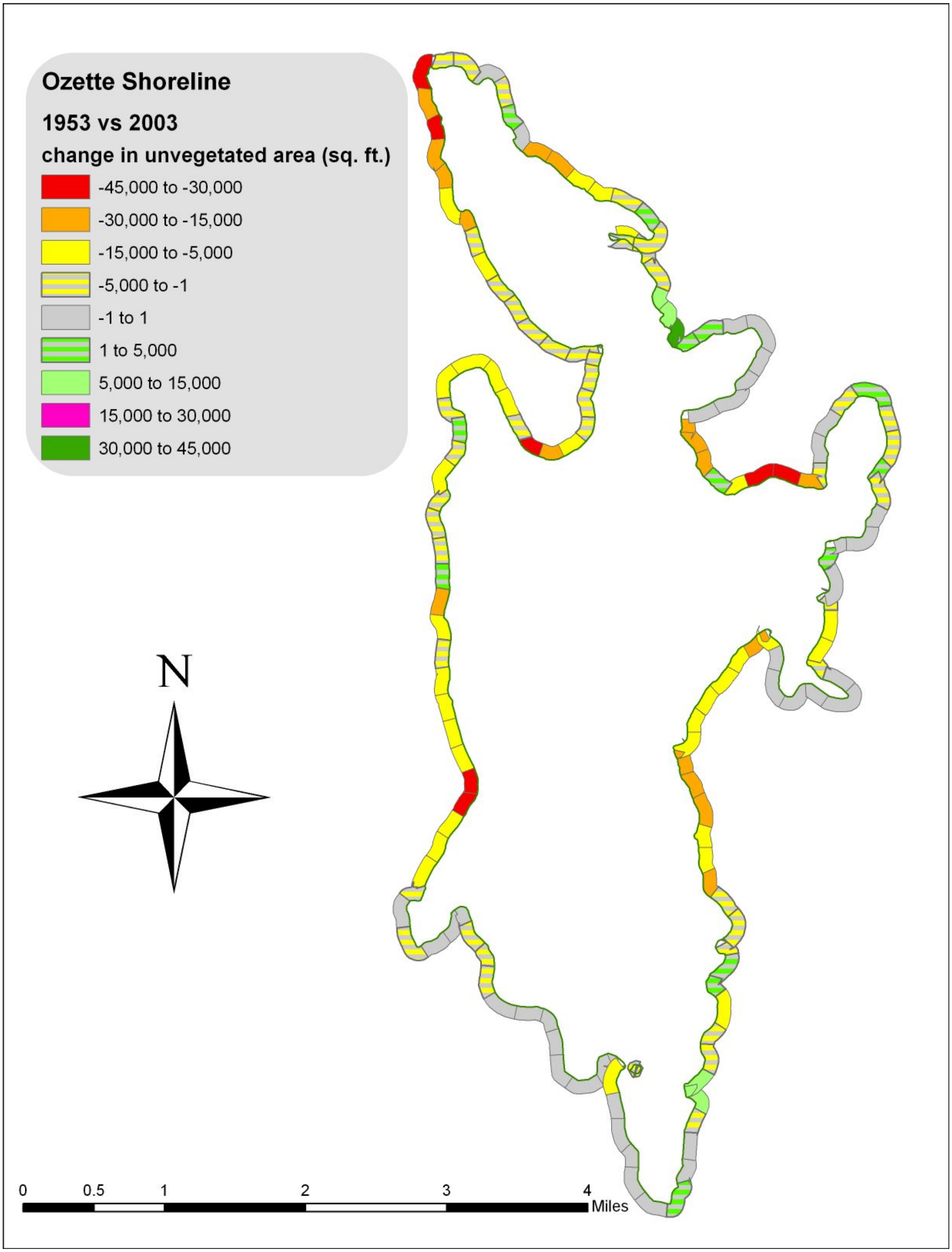

Figure 4.10. Change in unvegetetated area from 1953 to 2003 along overlapping 1,000 ft. segments of Lake Ozette shoreline.

Ritchie (2005) analyzed changes in vegetation only from 1953 to 2003. Significant changes to shoreline vegetation prior to 1953 may also have occurred. A news story from 1940 (Port Angeles Evening News, February 15, 1940) states, "*After the first big slaughter… [of elk] half a century ago the area that had been over-browsed started to grow up again, it was contended, and now all the lake [Ozette] shore and the adjacent country is a complete thicket…*". While aerial photos were taken in the 1930s to produce a topographic map for the War Department, an exhaustive search has failed to locate them. These photos, if found, will add valuable information about the evolution of shoreline vegetation, as well as sediment flux rates.

It is important to note that current and recent spawning locations, as well as vegetation and substrate conditions along the lake shoreline, may not be representative of past spawning distribution and shoreline conditions. The historical spawning distribution of beach spawning sockeye is not fully understood. Kemmerich (1926) stated that "*The shores of the lake afford many ideal spawning beds and over a large area, also numerous small streams of gravel bottom empty into the lake which are ideal spawning beds*". Kemmerich (1939) also recalled that, "*We made no special investigations of spawning beds during the years [1923-1926] but merely observed from time to time that most of the spawning seemed to be along the lake shore in suitable places and especially at the mouths of the several creeks*." Dlugokenski et al. (1981) observed sockeye spawning to the north Umbrella Creek during surveys in the late 1970s, but no sockeye have been observed spawning there since, despite exhaustive surveys. The spawning at the mouths of creeks described by Kemmerich (1939) is no longer observed. Meyer and Brenkman (2001) also observed sockeye spawning at Baby Island during the winter of 1994, but no sockeye have been observed spawning there since, also despite exhaustive surveys. The number of beach spawning aggregations that have been entirely eliminated remains unknown. Currently used spawning habitat at extant beaches (Olsen's and Allen's) and remaining available spawning habitat along the beaches appears able to produce only a small fraction of the population abundance that is thought to have once occupied the lake.

From the above historical observations and known habitat use by sockeye throughout their range, a larger picture of spawning habitat potentially used by sockeye in Ozette can be developed. Beach spawning habitat quality is controlled by substrate size and composition (i.e., gravel with interstitial spaces, low percentage fines), and intergravel circulation from lake current patterns (Blair and Quinn 1991; Hendry et al. 1995; Leonetti 1997) or upwelling hyporheic[11]- and/or groundwater (Blair et al. 1993; Burger et al. 1995; Young 2004). Historically, high quality spawning habitat was likely provided by numerous hydrogeomorphic situations:

1. Spawning on shallow non-vegetated beaches with suitable clean substrate exposed to wind-driven currents and wave action (Leonetti 1997).

[11] Note that for all text in the LFA, "hyporheic" is used to refer to water of mixed origin with no less than 10 percent and no more than 90 percent of either surface water or groundwater. The hyporheic zone is the surface/groundwater mixing zone. Groundwater does not = hyporheic water. Both can exist and differentially create seeps and springs.

2. Spawning at or near upwelling springs or seeps (hyporheic water or groundwater), regardless of water depth, where temperature regimes and intergravel flow are maintained. This reduces mortality during redd dewatering in shallow areas (Burger et al. 1995) or during times of little or no wind-driven current in deeper waters (Leonetti 1997).
3. Spawning at or near tributary inlet (deltas) with suitable substrate (deltaic gravel deposits), good intergravel circulation (upwelling hyporheic water and/or groundwater), and stable hyporheic temperature regimes (e.g., Umbrella Beach: Dlugokenski et al. 1981). Hyporheic water temperature regimes in tributary deltas would likely be slightly warmer and more stable than tributary temperatures, but cooler than warmer ambient lake temperatures or groundwater (White 1993; Edwards 1998).
4. Spawning in tributaries above deltaic zones.

4.2.2 Riparian Conditions

Riparian conditions around the lake are generally good to excellent, with the exception of the east portion of the North End where the county road parallels the shoreline, the north tip of the North End where most development has occurred, and a few parcels of private property where owners have constructed cabins or houses. Aerial photo analyses indicate that the area of vegetated shoreline below the winter high water level has increased since 1952 (Section 4.2.1). Increased shoreline vegetation may be limiting available spawning habitat, although the mechanisms responsible for this are not well understood.

Primary forest is the dominant riparian condition for most of the western half of the shoreline. Although abandoned homestead locations are known to exist in this area, they are virtually indistinguishable from undisturbed shoreline. Non-native vegetation (primarily reed canary grass) is generally limited to the mouth of Big River, some areas of Swan Bay, and near the lake outlet. Along the eastern half of the shoreline, a narrow buffer of mature trees exists between the lake and areas that have been clear-cut. On the North End, Rayonier Landing has remained unvegetated since at least the 1950s, and the current site of the ONP Ranger Station and campground has been subjected to ongoing disturbance since the USCG Life Saving Station was established at Lake Ozette in the 1940s. South of Swan Bay, an old railroad grade parallels the shore for some distance. Along the grade, shoreline conifers are mostly <50 years old, and the riparian area has a high proportion of mature red alder. This grade was constructed before 1952.

4.2.3 Water Quality

During the past 30 years several water quality attributes have been studied in Lake Ozette. In 1976, Bortleson and Dion (1979) examined several water quality attributes in the lake, including water temperature, dissolved oxygen, water transparency, and nutrients. Since then, others (Blum 1988; Beauchamp and LaRiviere 1993; Jacobs et al. 1996; Meyer and Brenkman 2001) have either collected water quality data or attempted to summarize data for Lake Ozette. Meyer and Brenkman (2001) and Beauchamp and LaRiviere (1993) both found that the lake begins to stratify in April and begins to mix in October. Isothermal conditions were found from December through February (Figure 4.11).

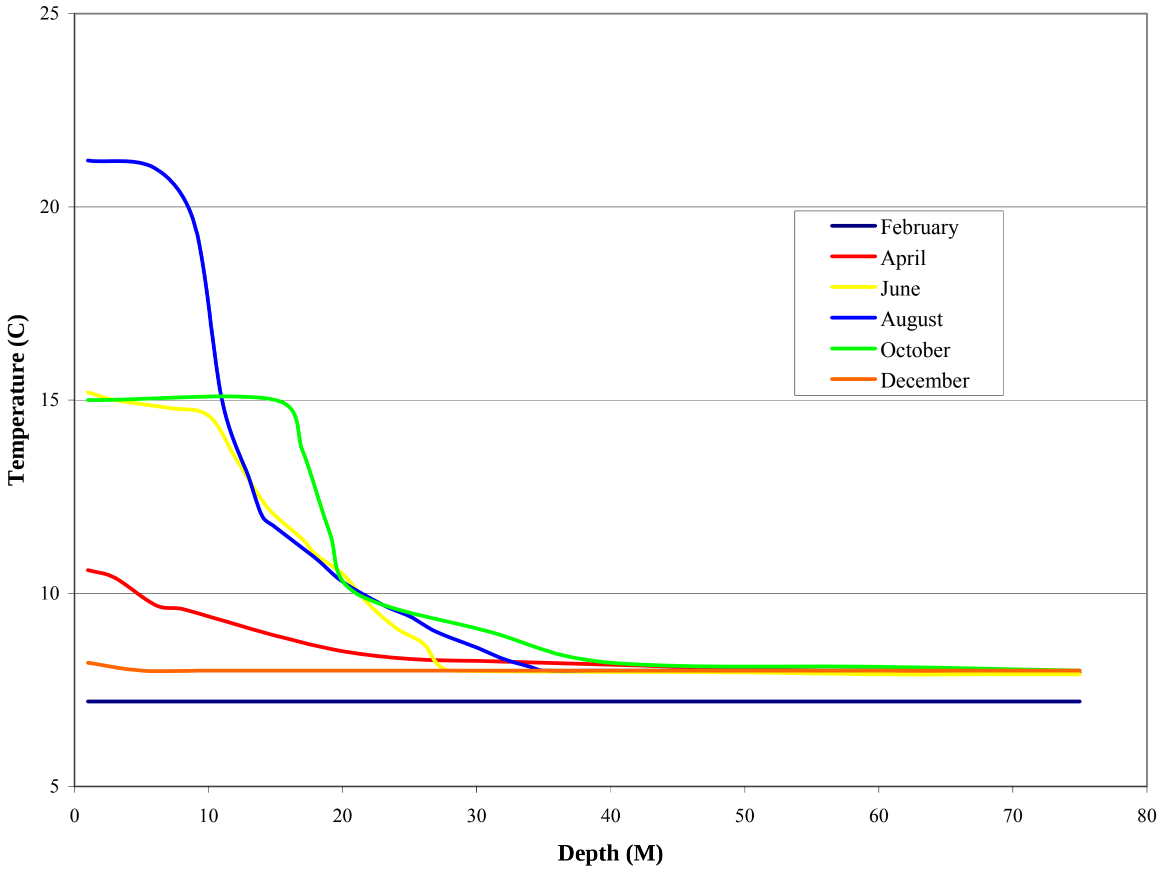

Figure 4.11. Seasonal variation in temperature-depth profiles for Lake Ozette (modified from Jacobs et al. 1996; source data: Meyer and Brenkman 2001).

Meyer and Brenkman (2001) reported dissolved oxygen levels ranging from 12.4 to 6.2 mg/l. Data collected by Meyer and Brenkman (2001) show a rapid decrease in dissolved oxygen in the lake's metalimnion from August through October. They found that dissolved oxygen levels rapidly increased in the hypolimnion. Jacobs et al. (1996) concluded that temperature and dissolved oxygen conditions do not appear to be a threat to sockeye salmon. Meyer and Brenkman (2001) concluded that temperature and dissolved oxygen conditions were well within the range preferred by sockeye salmon. Meyer and Brenkman (2001) also collected pH data during the summer of 1994. They found that pH levels ranged from 7.7 to 6.1 and that pH gradually decreased with depth throughout the monitoring period.

Water clarity has also been thoroughly examined in Lake Ozette. Water clarity can be divided into two main constituents: suspended materials and dissolved materials.

Turbidity is a measure of suspended materials, such as silt and algae. Color values are a measure of materials dissolved in water. Slightly different methods have been employed by different researchers attempting to describe water clarity in Ozette. Bortleson and Dion (1979) used water color and secchi-disk depth readings to describe Lake Ozette water clarity. They reported secchi-disk readings ranging from 2 to 4 meters, averaging 3 meters. Color reading ranged from 20-45 on Pt-Co scale. Meyer and Brenkman (2001) measured secchi-disk depths and turbidity in their study of water clarity. Meyer and Brenkman (2001) reported mean (from the four lake monitoring stations) secchi disk readings ranging from 3.7 to 6.5 meters. Meyer and Brenkman (2001) speculated on the higher clarity observed in 1994 as compared to 1976 and thought that at least in part it was due to the lower zooplankton densities observed in 1994. Meyer and Brenkman (2001) also monitored turbidity levels in Lake Ozette and reported a range of 1.4 to 18 NTUs at their four monitoring stations in the lake. They concluded that turbidity levels tend to be low in the lake with two exceptions: during May and June when plankton blooms are occurring and after storm events. The highest turbidities recorded in the lake were made a few days after a storm event. Turbidity levels of 35 NTUs were measured in the middle of Swan Bay. During this sampling period they found turbidity decreased with depth. Turbidity levels at 13 meters were 14 NTUs.

Nutrients were also sampled by Bortleson and Dion (1979) and Meyer and Brenkman (2001). Meyer and Brenkman found that Kjeldahl-N, total dissolved phosphorus, orthophosphate-P, and ammonia-N did not demonstrate any consistent patterns in concentration with increased depth. They also found that concentrations of nitrate did not change with increased depth in January, but the lowest concentrations occurred near the lake surface in samples collected in May, July and August. Table 4.2 is a comparison of average winter/spring and summer/fall values for organic and inorganic nitrogen, total phosphorus, and orthophosphate phosphorus collected in 1976 and 1994. Based upon data collected in 1976 and 1994, Lake Ozette can be described as an oligotrophic to mesotrophic system (low to moderate levels of nutrients; Jacobs et al. 1996). Meyer and Brenkman concluded that Lake Ozette is likely phosphorus limited.

Table 4.2. Comparison of inorganic nitrogen, organic nitrogen, total phosphorus, and orthophosphate from samples collected in 1976 and 1994 for three separate depth zones (source: Bortleson and Dion 1979; Meyer and Brenkman 2001).

	Winter-Spring (1976)			Winter-Spring (1994)		
	0-25m	10-50m	22-80m	1m	18m	22-64m
Inorganic Nitrogen (mg/l)	0.150	0.140	0.160	0.137	0.156	0.169
Organic Nitrogen (mg/l)	0.110	0.110	0.120	0.115	0.101	0.103
Total Phosphorus(mg/l)	0.008	0.007	0.008	0.006	0.006	0.005
Orthophosphate (mg/l)	0.004	0.003	0.004	0.002	0.001	0.002
	Summer-Fall (1976)			**Summer-Fall (1994)**		
	0-25m	**10-50m**	**22-80m**	**1m**	**18m**	**22-64m**
Inorganic Nitrogen (mg/l)	0.060	0.110	0.130	0.059	0.168	0.171
Organic Nitrogen (mg/l)	0.130	0.140	0.120	0.110	0.098	0.105
Total Phosphorus(mg/l)	0.008	0.008	0.007	0.008	0.009	0.010
Orthophosphate (mg/l)	0.003	0.003	0.004	0.001	0.001	0.001

4.2.4 Lake Productivity

Healthy and abundant zooplankton communities are a critical component of the overall sockeye smolt production in any lake. Zooplankton communities are dependent upon phytoplankton communities. Bortleson and Dion (1979) used chlorophyll α concentrations measured in Lake Ozette to estimate algae concentrations in the lake, and algae growth potential was tested using algal bioassay tests. They found that chlorophyll α concentrations were highest in the summer (averaging 3.5μg/l) and lowest (1.2-0.3μg/l) in the winter. Meyer and Brenkman (2001) report chlorophyll concentrations of 7.6 to 11.5 mg/m^3 in the upper five meters of the lake during April and May and concentrations of 0.4 to 0.6 mg/m^3 at 20 meters depth during the same period. Samples collected in 1976 indicated that the algal population in Lake Ozette is dominated by *Botryococcus* during all months except May (Bortleson and Dion 1979). Meyer and Brenkman (2001) concluded that Lake Ozette can be classified as oligotrophic based upon concentrations of chlorophyll.

Meyer and Brenkman (2001) concluded that most of the chlorophyll in Lake Ozette is in the upper water column. Copepod and cladoceran densities from surveys conducted by Meyer and Brenkman (2001) indicate that densities are 3 times higher in the upper 5 meters than in the zone from 5 to 30 meters. Dlugokenski et al. (1981) calculated an average density of 7.4 copepods and cladocerans per liter of water. Densities reported by Meyer and Brenkman were much lower. Meyer and Brenkman (2001) described the Lake Ozette zooplankton community as composed of nine crustacean and 15 rotifer taxa. Several other researchers have studied and described the Lake Ozette zooplankton community. Dlugokenski et al. (1981) found the copepods and cladocerans made up 57 to 99.8% of the organisms in monthly samples.

They found that *Diaptomus sp*., *Epischura sp*., and copepods of the genius cyclopoida were present in all samples, as were *Bosmina sp*., *Daphnia sp*., *Holopedium sp*., and *Leptodora kindtii*. Bortleson and Dion (1979) found similar zooplankton assemblages and that densities were highest from May to November and lowest from February to April. Jacobs et al. (1996) found through an extensive review of Ozette literature that all researchers who have studied zooplankton communities in Lake Ozette have concluded that sufficient food supplies are available for juvenile sockeye salmon during their period of lake residence. Beauchamp and LaRiviere (1993) used bioenergetic simulations and cladocerans egg-ratio analysis to predict that consumption demand by kokanee and juvenile sockeye could be satisfied by less than 1% of the instantaneous production of the preferred large Daphnia throughout the growing season. Dlugokenski et al. (1981) evaluated the length and weight of Ozette sockeye smolts and concluded that they were the third largest yearling sockeye smolts in the world, providing additional evidence that zooplankton populations are not limiting sockeye productivity.

4.2.5 Hydrology and Lake Level

The hydrology of the Ozette Watershed has been poorly studied over the contemporary settlement period of the Ozette region. However, an assortment of lake level, climate, and hydrology data has been collected at various places in the watershed and coastal region, for different reasons, that can be massed together to highlight the major physical patterns of the lake's hydrology. The USGS made several miscellaneous measurements of instantaneous stage discharge in the watershed's tributaries in the 1960s and 1970s (Bortleson and Dion 1979) and maintained a continuous stream gage on Ozette River at the outlet of Lake Ozette between 8/1/1976 and 9/30/1979 (Figure 4.12). The stream gage station consisted of a continuous stage (level) recorder and periodic discharge measurements (using a current meter) to develop a stage-discharge rating curve. The stage recorder and backup stage plate were located approximately 100 feet upstream of the new footbridge (circa 1976) that crosses Ozette River. The stream gage effectively measured both lake and river stage, as the gage was located at the transition zone between lake and river, where lake water converges into the river. These data will be described in more detail in Section 4.3.6.

In 1981, the Olympic National Park (ONP) partially continued previous efforts by the USGS and began recordings of manual daily lake stage at the same USGS stage plate at the head of the Ozette River and outlet of the lake (Figure 4.12). The ONP personnel recorded stage at this location manually every day from 11/1/1981 to present (or 9/30/2002 used here). A gap in the data exists between 9/20/1994 and 12/31/1997, and daily records are missing for other parts of the record, with gaps ranging from a day to several weeks. ONP personnel recorded stage only once daily at random or convenient time periods. Time of day was not recorded in their database. Lake Ozette does fluctuate on a daily basis, especially during windy periods, because of wind seiche. However, due to the large volume of the lake and partial storage and attenuation of inflows, the lake does not experience dramatic level fluctuations at the daily time scale, except during extremely high discharge (flow) input events or large wind seiches. Daily ranges of stage change are less than 0.5 feet. While these data from this ONP gage do not represent daily averages, the data, in mass, can be assumed to be a reasonable surrogate for mean daily stage. Gaps in the stage record were filled in through linear interpolation between adjacent data points by Makah Tribe Fisheries personnel. Gaps larger than 10 days were not interpolated and left blank. Thus, the long but discontinuous stage record was recovered for the period 1982-2002.

In March 2002, MFM personnel installed a continuous stage gage near the same location as the historical USGS gage. This gage is located 30 feet above the footbridge and 70 feet below the USGS/ONP manual stage plate. This gage automatically measures and records lake (or river) stage every 15 minutes. These data were averaged to create mean daily lake stage, comparable to the ONP daily stage recordings. Thus daily lake stage data are available from 1976 to 2005 (Figure 4.13).

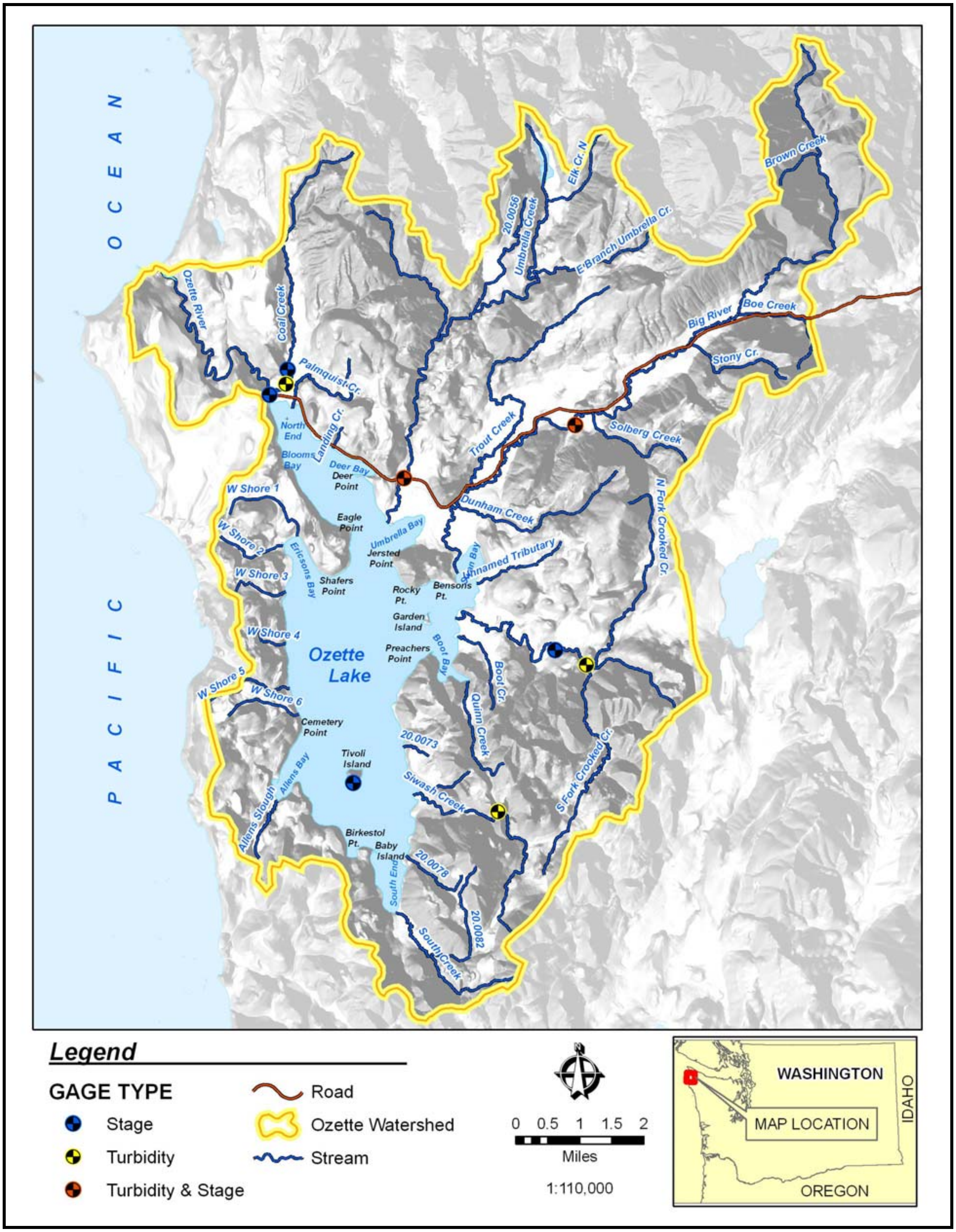

Figure 4.12. Locations of Lake Ozette watershed stream and turbidity gages operated by MFM.

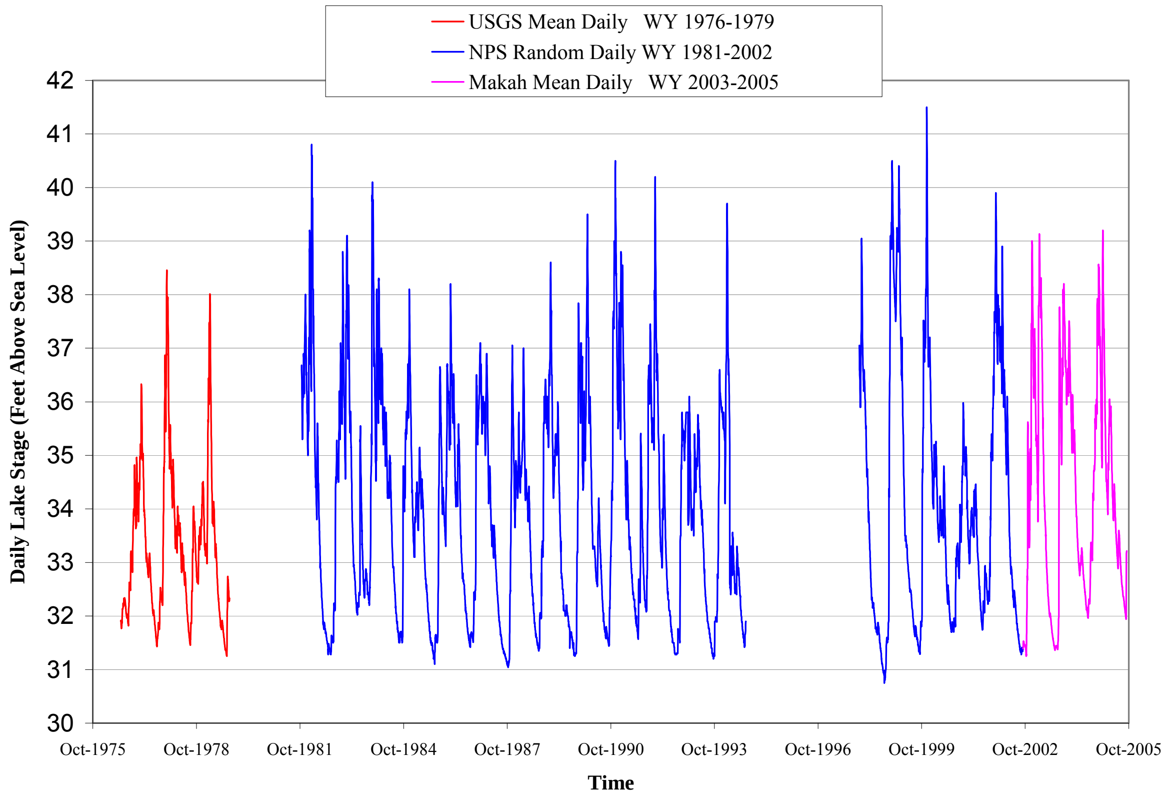

Figure 4.13. Lake Ozette stage hydrograph, 1976-2005 (source: USGS, ONP, and MFM lake stage data).

The mean surface elevation of the lake for the period of record (1976-2005) was 33.98 feet above mean sea level (National Geodetic Vertical Datum of 1929). Annual lake level fluctuations ranged from an average minimum of 31.3 feet (30.75 lowest recorded) to an average maximum of 38.6 feet (41.5 highest recorded) above mean sea level (Figure 4.13). Hydrographs of the lake stage (level) generally follow the same seasonal patterns as average monthly rainfall displayed in Figure 1.5. Peak lake levels occur during the wettest months between November and April, while low lake levels occur during the dry season between July and September (Figure 4.14 and Figure 4.15). Figure 4.14 displays the level regime of Lake Ozette and different percentiles that the lake has achieved between 1976 and 2005. Example lake hydrographs for various wet, average, and dry precipitation years are displayed in Figure 4.15, while Figure 4.16 displays level duration curves for those same years.

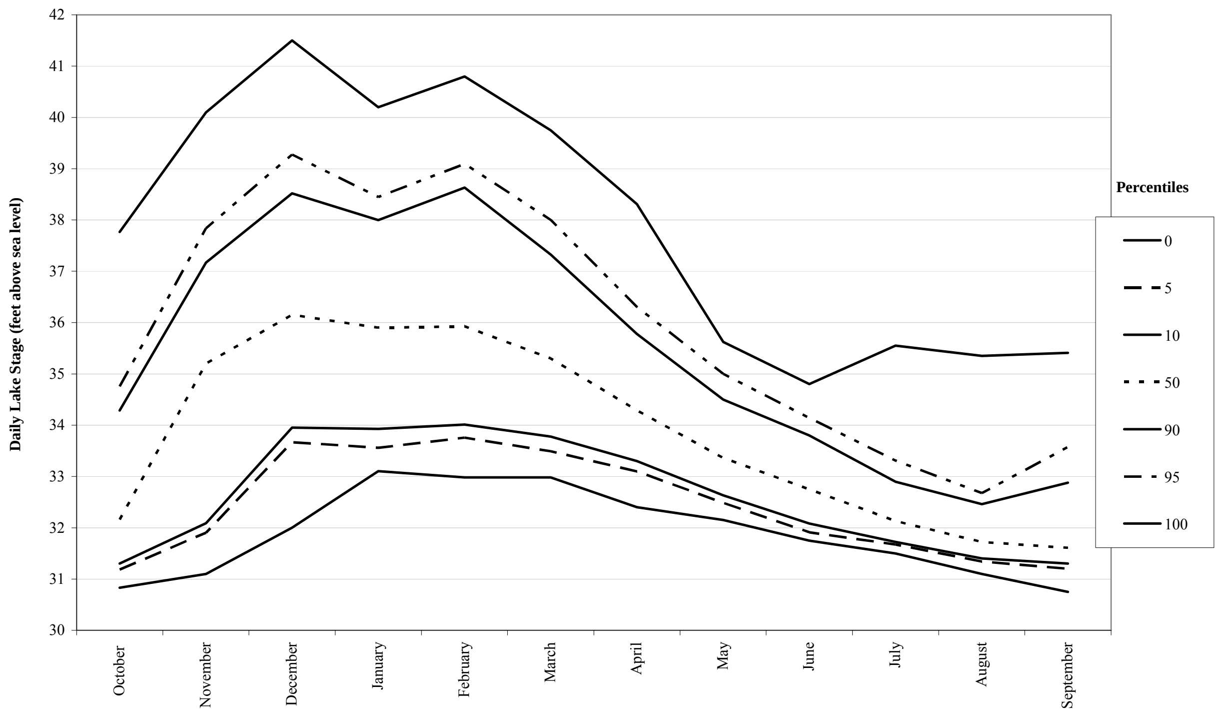

Figure 4.14. Lake Ozette water level duration curves for the period 1976 through 2005 (source: USGS, ONP, and MFM lake stage data).

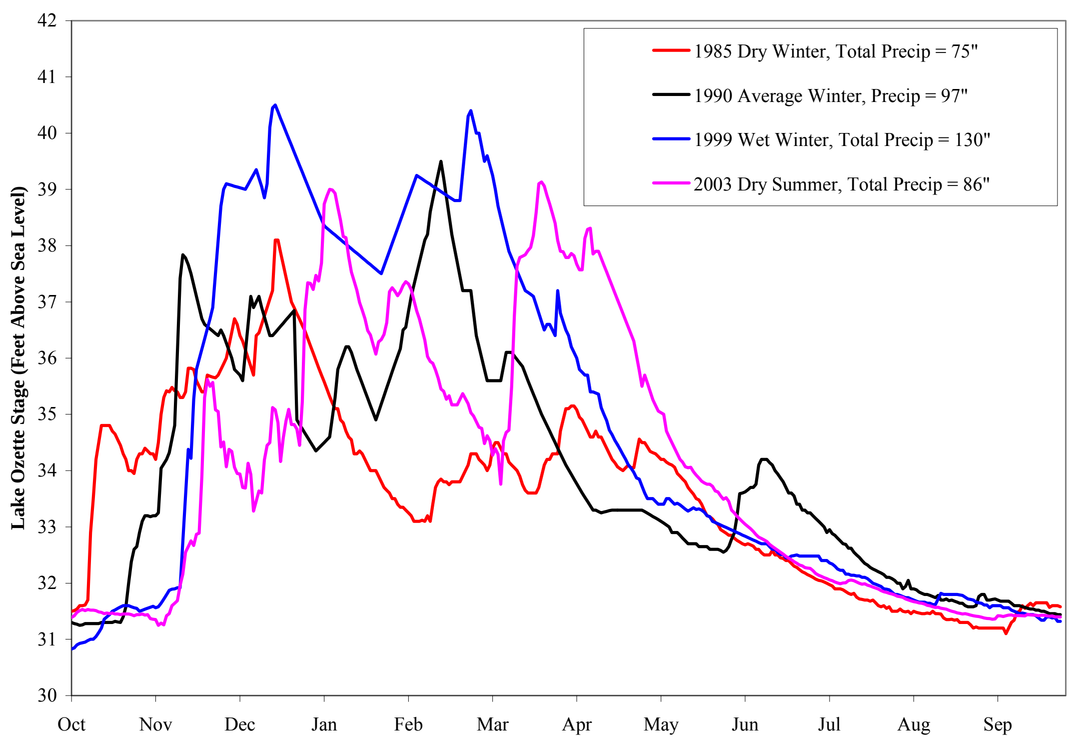

Figure 4.15. Sample Lake Ozette hydrographs for 1985 (dry winter), 1990 (avg. winter), 1999 (wet winter), and 2003 (dry summer) (source: USGS, ONP, MFM).

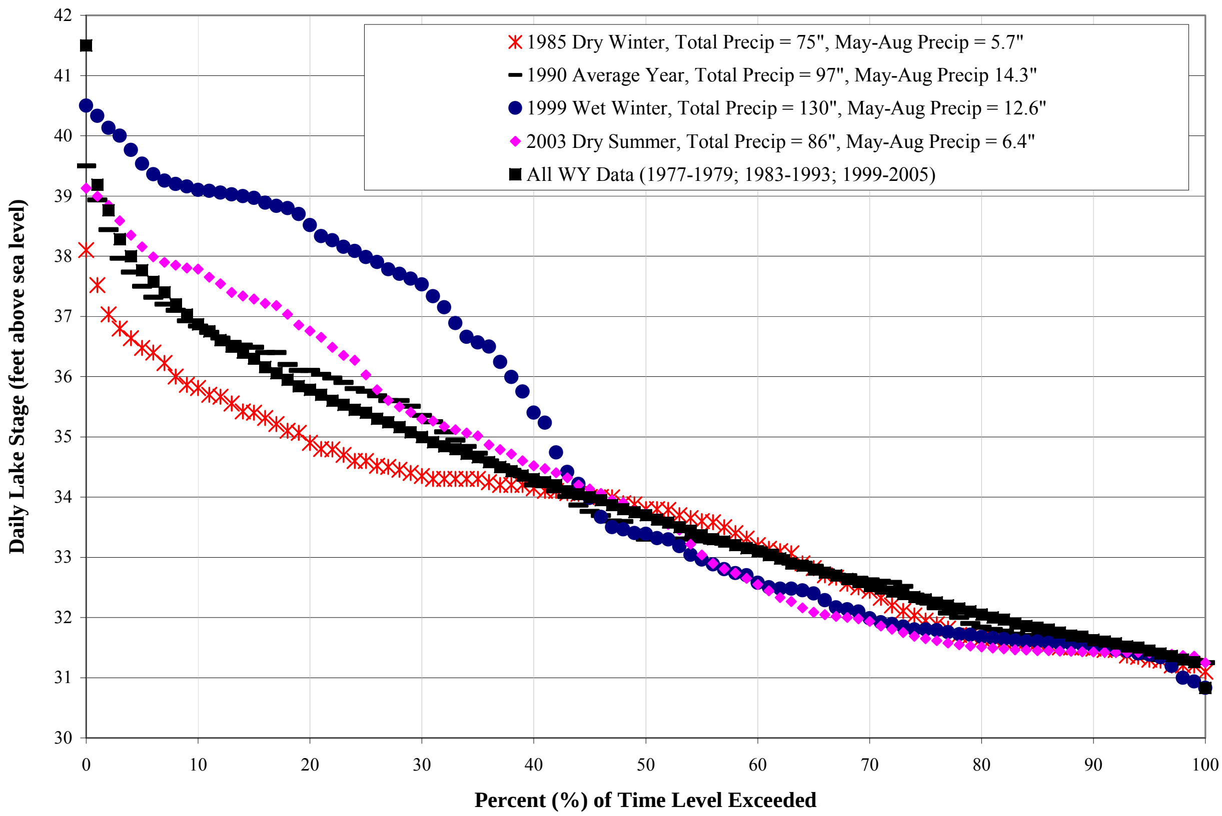

Figure 4.16. Lake Ozette level duration curves for 1985 (dry winter), 1990 (average winter), 1999 (wet winter), 2003 (dry summer), and all water years (1983-1993; 1999-2005) (source: USGS, ONP, and MFM).

Stage (flood) frequencies of both annual maximum and minimum lake stages from values depicted in Figure 4.17 and Figure 4.19 were calculated using a Log-Pearson Type III distribution and other standard techniques outlined by the U.S. Water Resources Council (1981). Estimates based on these data are outlined in Table 4.3. However, it is very important to note that these data represent stage frequency conditions under varied lake outlet (Ozette River) hydraulic conditions throughout the period of record (1976-2005). Historically, LWD was removed extensively from the Ozette River by early settlers and by the WDF (Kramer 1953), and to a lesser extent by local citizens post 1953. Wood removal from the Ozette River has likely affected the lake level regime (stage magnitude, frequency, duration and timing) of Lake Ozette (PWA 2002; Herrera 2005). Thus, these frequency estimates can be used only to understand conditions within the period of record.

Stage or flood frequency predictions *outside this period of record*, into the past or future, should be conducted with caution, especially as wood loads and channel boundary conditions in Ozette River recover toward pre-disturbance conditions. In addition, sediment deposition at the mouth of Coal Creek within Ozette River, between 1979 and

2003, has likely altered stage magnitude, frequency, duration and timing conditions of Lake Ozette stage *within the period of record* 1976 to 2003. However, the exact effect of these sedimentation changes on the lake level regime is unanalyzed, and is likely much less than the effects of wood removal historically.

Table 4.3. Lake Ozette stage frequencies for the period of 1976-2005, using weighted skew coefficients (source: Shellberg 2003).

Return Interval (Years)	Frequency	Annual Maximum Stage (Feet)	Annual Minimum Stage (Feet)
1.01	0.99	35.21	32.1
2	0.5	38.84	31.43
5	0.2	40.1	31.19
10	0.1	40.74	31.07
20	0.05	41.27	30.97
25	0.04	41.42	30.94
50	0.02	41.85	30.86
100	0.01	42.24	30.78
	Station Skew	-0.40	-0.06
	General Skew	0.2	0.20
	Weighted Skew	-0.17	0.05

Maximum annual lake stage (Figure 4.17) is strongly correlated with total wet season precipitation during the period October through April (Figure 4.18). This trend is also evident in the level duration curves in Figure 4.16, which shows that the duration of time water exceeds a given level is higher than average during a very high (wet) precipitation year (1999). However, during this same wet year (1999), high-exceedence low lake levels were below average, indicating a summer precipitation control on low lake levels and a limit on winter storage carryover into summer.

Minimum annual lake stage (Figure 4.19) is very weakly correlated (r^2 = 0.018) with total precipitation during the preceding water year and winter wet season, largely due to the limit of water storage following the winter mass of precipitation and discharge input to the lake. In contrast, late summer Lake Ozette stages are more strongly correlated to total precipitation (r^2 = 0.635) during the summer months (July to September) (Figure 4.20). This indicates that summer rain, along with the associated mild weather and reduced evaporation and transpiration, control the recession of the lake stage and ultimately the low lake and river discharge levels. Furthermore, the transient fog belt along the coast during the summer also likely has a strong but unquantified effect on evaporation losses and thus ultimate summer lake level (see Figure 4.16 and Section 1.3.2). While long-term lake storage and carryover of water from the winter wet season into the summer dry season is weak, the relatively large Lake Ozette basin (7,550 acres) still has an enormous impact on water storage and release up to the seasonal (3 month) time step, creating a unique hydrologic signature for both Lake Ozette water levels and Ozette River discharge.

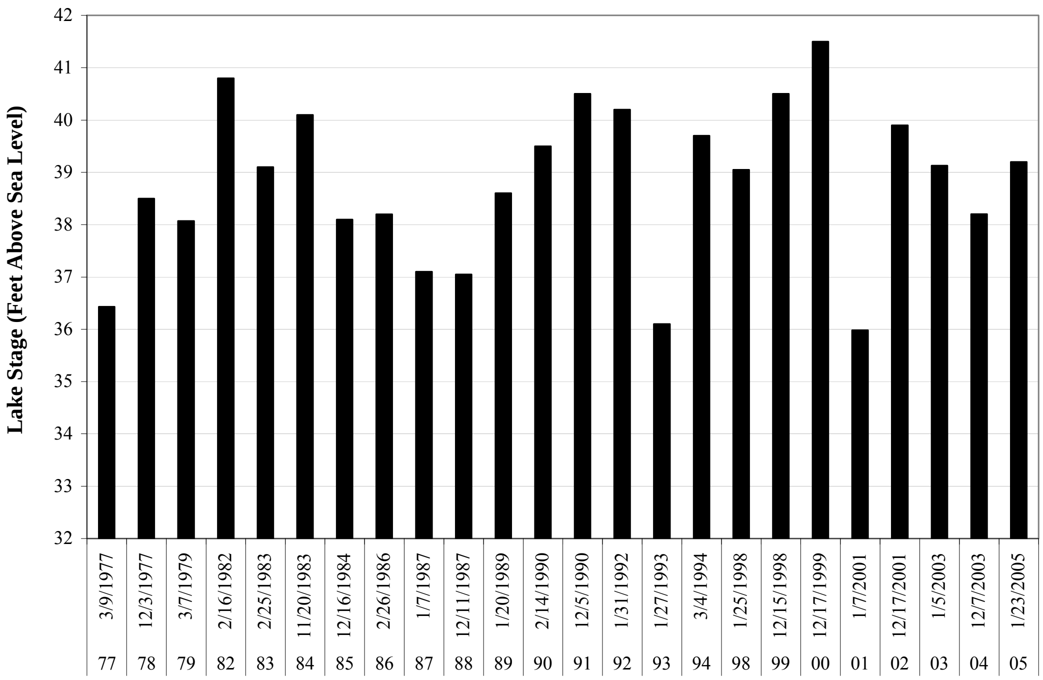

Figure 4.17. Lake Ozette annual maximum lake level for the period of record (source: USGS, ONP, and MFM lake level data).

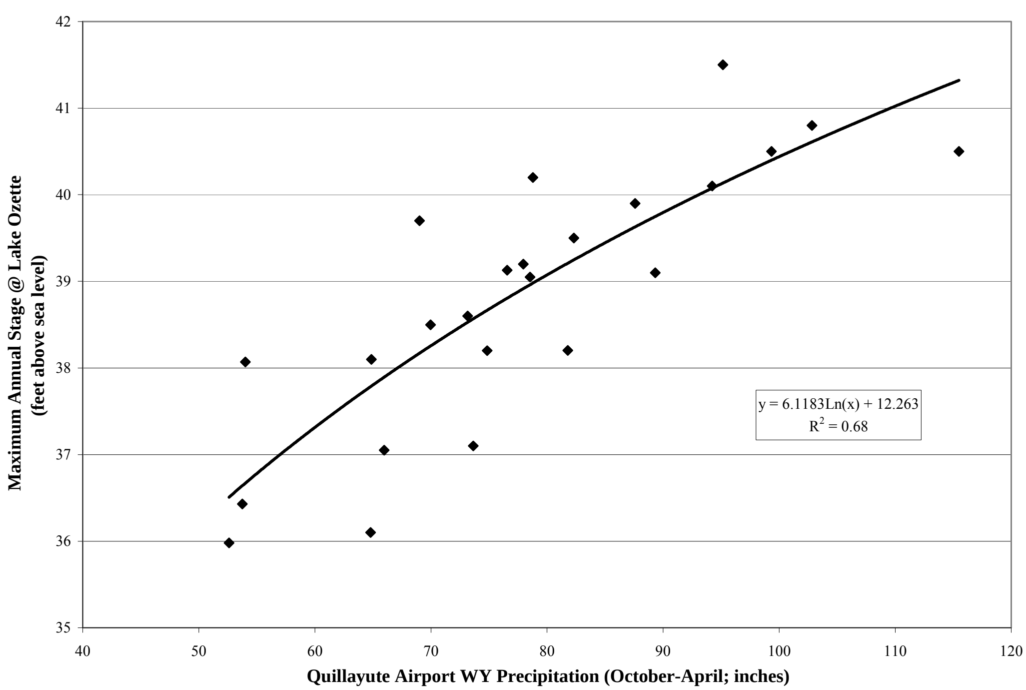

Figure 4.18. Regression of maximum annual stage and winter precipitation (October through April) (source: USGS, ONP, and MFM lake level data).

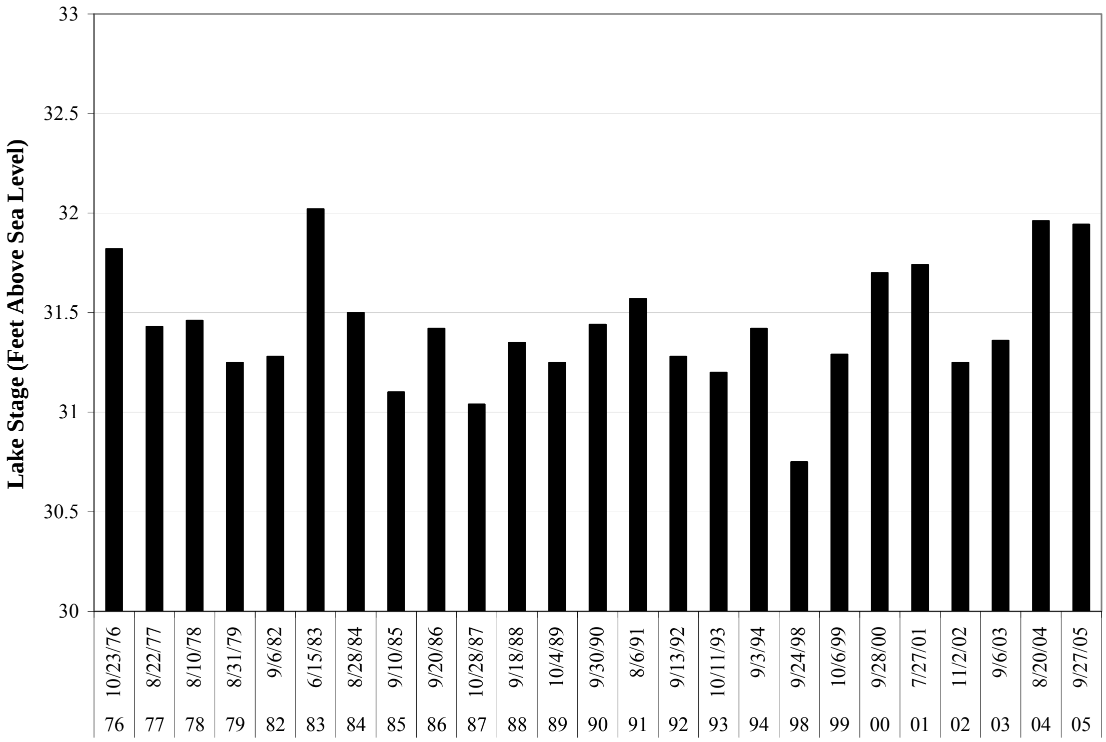

Figure 4.19. Lake Ozette annual minimum lake level for the period of record (source: USGS, ONP, and MFM lake level data).

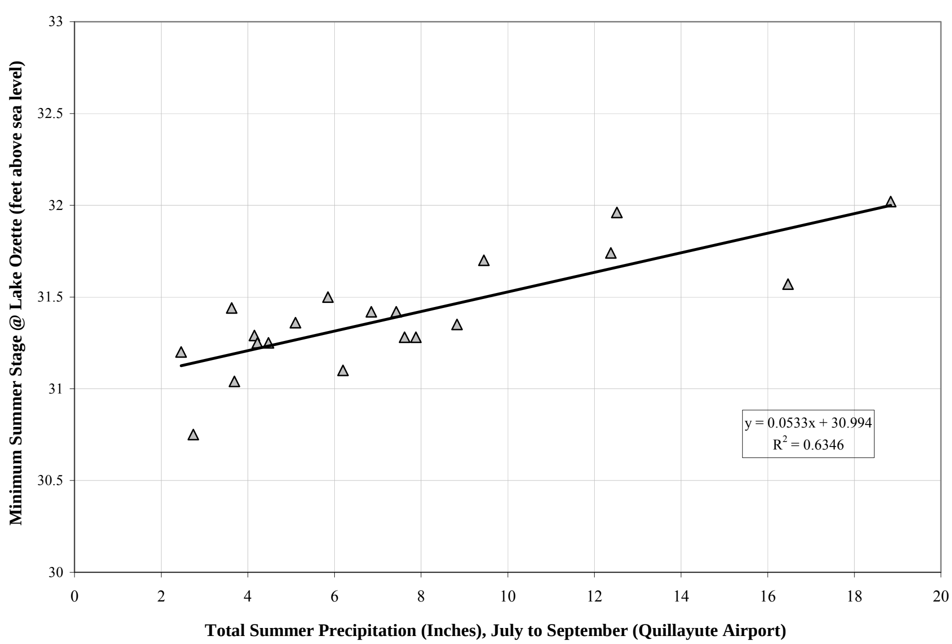

Figure 4.20. Regression of minimum annual stage and summer precipitation (July through September) (source: USGS, ONP, and MFM lake level data).

To display the storage effect of Lake Ozette, the average timing (mean date) of peak discharge and lake stage events was calculated and plotted in polar coordinates (Figure 4.21), following methods outlined in Castellerin et al. (2001) and Shellberg (2002). Stream gaging data from watersheds around the Olympic Peninsula were selected to compare to Lake Ozette. For all watersheds except Lake Ozette, the peaks over threshold (POT) data were obtained from the USGS, which contains all major flood peaks above the "base discharge" calculated by the USGS (Novak 1985). To insure independence, peaks within ten days of each other were filtered out of the data set, leaving only the largest of numerous close peaks. For Lake Ozette, the dates for the annual maximum lake stage were used to calculate the average timing of peak lake levels, since a base discharge (or stage) was not available. In addition, this allows for the analysis of response and timing delay of the highest annual Lake Ozette peak stages from multiple discharge input events.

For Figure 4.21, the distance around the circumference of the polar plot, θ_t, is the average timing or date of n distinct peak events. The distance from the center of the polar circle, r_t, is the vector magnitude associated with that average. The magnitude of r_t is a measure of the regularity or variability of the distinct events. Values range from zero to one, with high values indicating a strong seasonality (low variability around the mean date) and low values indicating weak seasonality (high variability around the mean date)

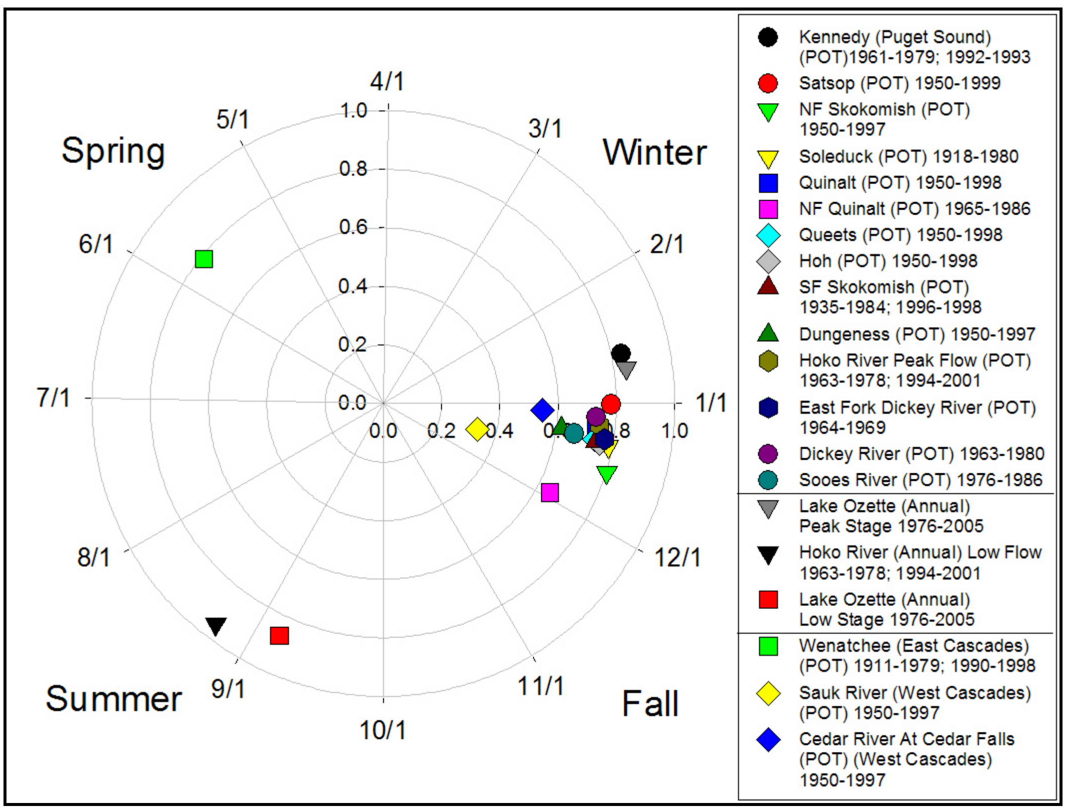

Figure 4.21. Average timing of distinct flood or low flow events for Washington State streams (sources: USGS, ONP, and MFM).

The average peak stage date for Lake Ozette is January 13 with r_t= 0.84, indicating a strong seasonality to winter peak events. The closest long-term USGS gage to Ozette is located on the Hoko River, which has an average peak discharge date of December 21 with r_t = 0.74, also a strong seasonal signal. The Hoko River is a decent surrogate for inflow conditions to Lake Ozette, since the Hoko River shares similar headwaters with the largest Ozette tributary, Big River. On average, there is a 22-day delay between average peak events in the Hoko vs. Lake Ozette. However, this is not to say that there is an average 22-day delay between a given peak flood and a given peak response in Lake Ozette, but rather that it takes roughly 22 days longer for Ozette to ramp up to its full annual peak level compared to when typical peak river levels occur in the nearby Hoko River. Lake Ozette peak levels are a response of 1) peak inflow water volume, 2) recession and base flow contributions following (or between) a given event, 3) multiple input events of various size that can interact because of antecedent conditions, and 4) lake outlet conditions that change infrequently. Thus, peak levels in the lake are a response of multiple flow events of various size and spacing, which build up to the peak lake level, on average, 22 days after the average peak inflow timing.

A stage-area-volume relationship for Lake Ozette was developed to understand how the lake surface area and volume of storage vary with fluctuations in lake levels (Figure 4.22). This relationship provides the linkage between modeled water surface elevations in Ozette River, particularly at the upstream boundary (or lake spillway) with lake elevation. Figure 4.23 illustrates the modeled relationship between lake stage and surface area.

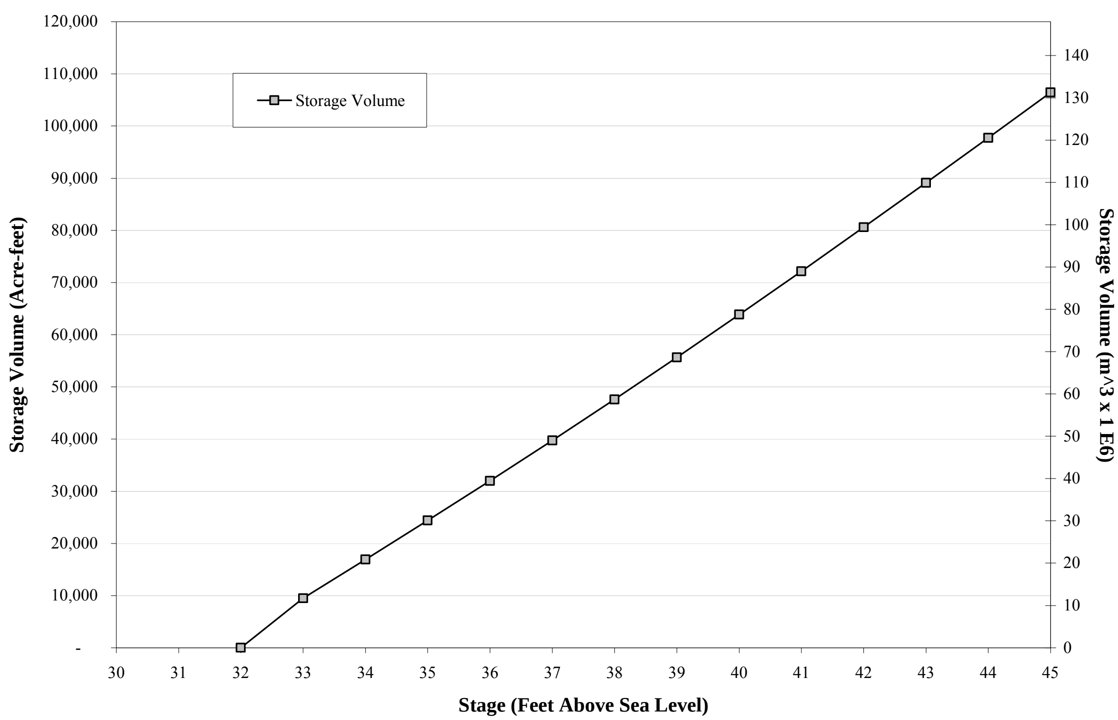

Figure 4.22. Stage-area-volume relationship for Lake Ozette based upon LiDAR data and modeled shoreline (modified from Herrera 2005).

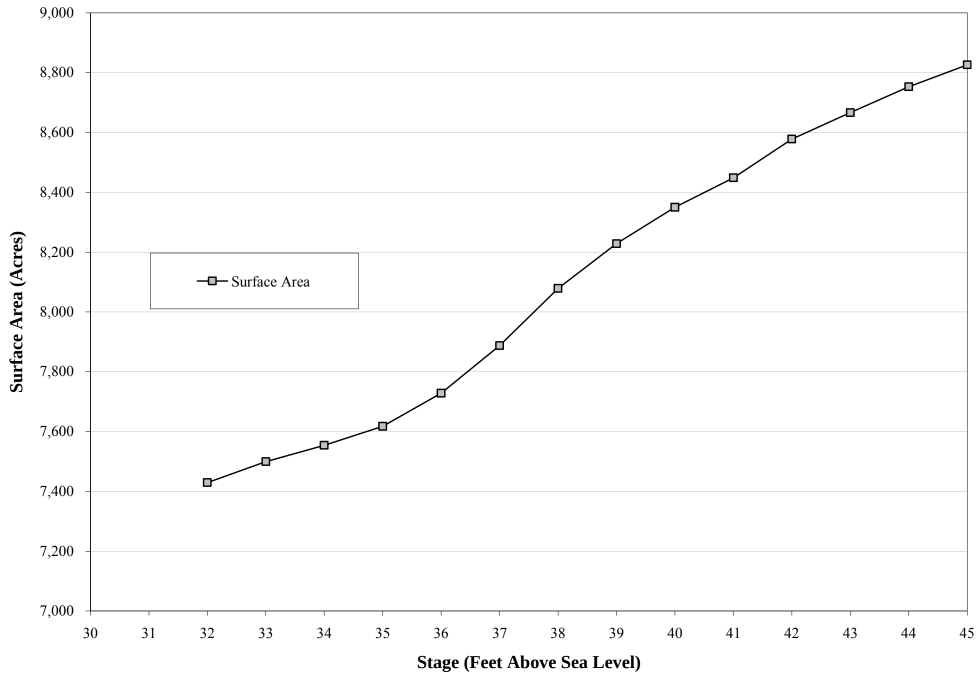

Figure 4.23. Lake Ozette surface area versus stage relationship (modified from Herrera 2005).

Finally, the knowledge of the dynamics of the water surface elevation of Lake Ozette cannot be complete without a brief discussion of the wind seiches that are known to occur at Lake Ozette. A wind seiche is a wave that oscillates in lakes, bays, or gulfs from a few minutes to a few hours to a few days (maximum) as a result of seismic or atmospheric disturbances. The initial displacement of water from a level surface can arise from a variety of causes, and the restoring force is gravity, which always tends to maintain a level surface. At Lake Ozette, it is the strong southwest wind blowing over the enclosed basin that produces a displacement of the surface elevation. Surface waters are pushed to the downwind lakeshore, typically the north and northeast shores. When the winds diminish, the accumulated water along the downwind shoreline flows back across the lake to the south and begins oscillating. This causes rising and falling water levels on both sides of the basin. With each circuit across the lake, the seiche diminishes in height, eventually damping out into background lake motions. Like the striking of a bell, it takes only one disturbance event to begin the wave action of a seiche. Once formed, the oscillations are characteristic only of the geometry of the basin itself and may persist for many cycles before decaying under the influence of friction.

In the fall of 2003, MFM installed a lake stage (level) gage at the south face of Tivoli Island near the south end of the lake (Figure 4.12). Since historical lake levels were always taken at the north end of the lake within the converging Ozette River head, a true lake recorder was installed at the south end to both validate existing data at the north end of the lake and uncover additional lake level dynamics that may influence such factors as shoreline erosion and sockeye beach spawning habitat. Figure 4.24 displays the hydrographs for both the North Lake Ozette stage recorder and South Lake Ozette stage recorder at Tivoli Island. At the daily time step, these gages are virtually identical. However, at the hourly or instantaneous time step, significant deviation is observed between the gages, as indicated by the stage "noise" associated with the hydrograph. This noise is a reflection of the wind seiche. By subtracting stage data at the north end of the lake from data at the south end of the lake (Tivoli minus Ozette River), at the 15-minute time step, the instantaneous wind seiche patterns become apparent (Figure 4.25). Within Figure 4.25, negative values of "Tivoli minus Ozette River Stage" indicate that water is displaced toward the north end of the lake as compared to the south. The opposite is true for positive values, when the seiche wave propagates back toward the south end of the lake. These differences are denoted by sharp spikes and usually last less than several hours. Absolute differences up to 0.5 feet are observed as seiche heights, but common values typically range between 0.1 and 0.2 feet. Wind seiche magnitudes are stronger in the negative direction to the north, as the initial water surface elevation disturbance is typically from a strong southwest wind pushing water northward. This north-south wind seiche relationship is slightly affected by changing hydraulic conditions at the head of Ozette River, since the stage gage there is located in the transition zone between the lake and river. During periods of high river discharge, the relative average stage at the Ozette River gage drops up to 0.1 feet below the average stage at Tivoli, as displayed by the changing zero equilibrium line between the north and south gages (Figure 4.25). This is an artifact of increases in water surface slope through the gage reach as discharge increases, which decreases the absolute stage as compared to Tivoli Island.

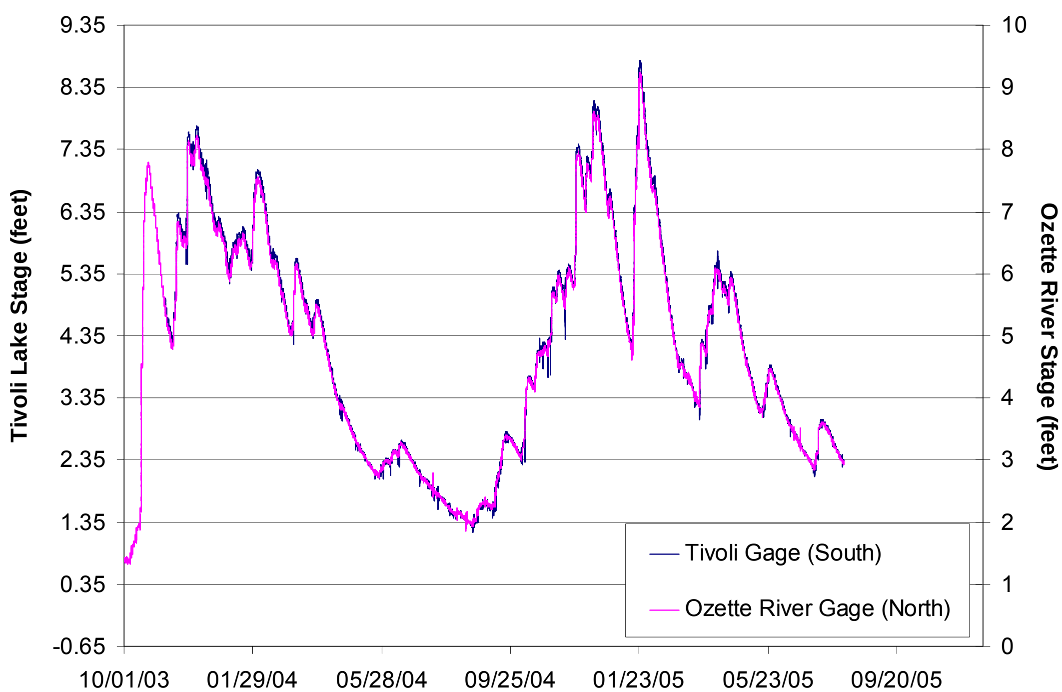

Figure 4.24. Lake Ozette stage at North Ozette (River) and South Ozette (Tivoli Island) (source: MFM unpublished lake level data).

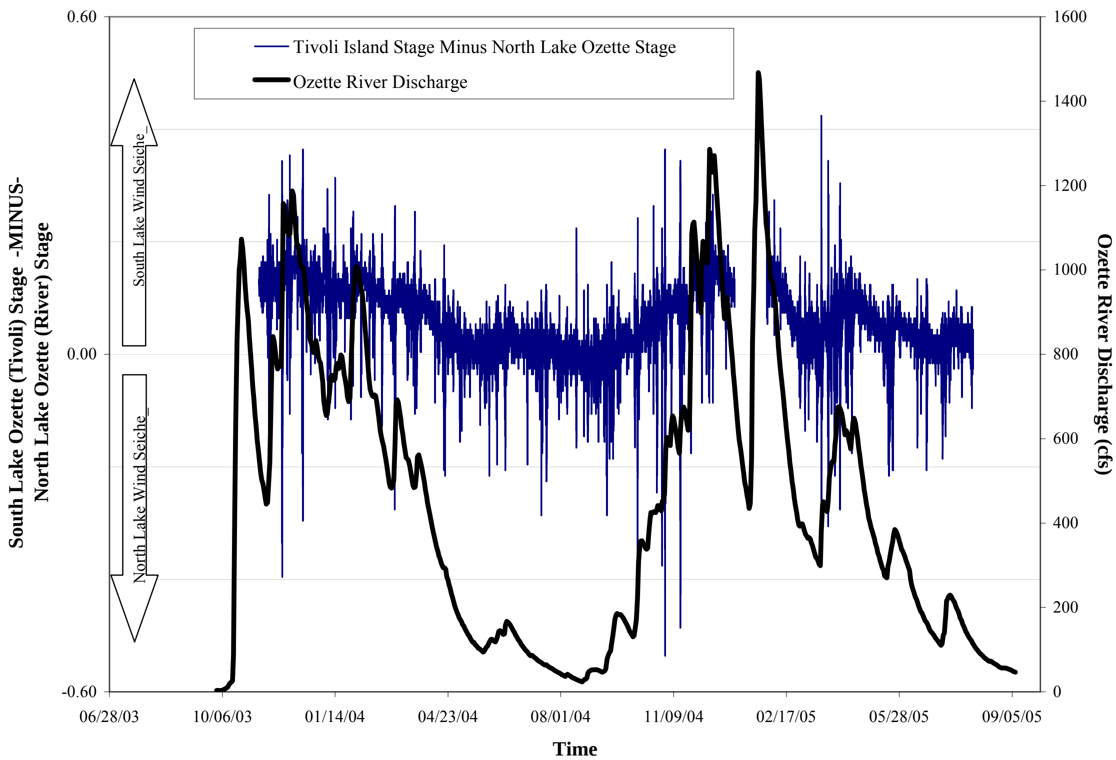

Figure 4.25. Instantaneous (15-minute) wind seiche differences contrasted with Ozette River discharge (source: MFM lake and river stage data).

4.3 OZETTE RIVER

The Ozette River is unique compared to other Olympic Peninsula rivers. The river is very low gradient (0.1%), dropping approximately 32 feet (10 m) in elevation over a distance of 5.3 miles (8.5 km) from the lake to the ocean. Minimum stream bed elevations and water surface elevations for various lake stages are depicted in Figure 4.26. Lake Ozette forms an efficient sediment trap, trapping all but minor amounts of suspended sediment entering the lake from tributaries. The topographic low in the channel of the extreme upper Ozette River, between the lake's outlet and Coal Creek, indicates that coarse sediment from the lake is not being transported downstream into the river (Herrera 2006). Therefore, the only sources of coarse sediment to the Ozette River are a handful of small tributaries, bank erosion, and Coal Creek (the river's largest tributary). The outlet is quite interesting; the river maintains an average depth of 3 to 4 meters (10-13.3 ft) during low flow for a distance of almost 200 meters (650 ft). The overall very low gradient and low energy of the lake outlet influence channel processes and fish habitat conditions to a large extent. Figure 4.27 depicts a typical channel cross-section from the upper Ozette River that is typical of the lake-to-river transition zone at the lake outlet, but not of the fluvial portions of Ozette River.

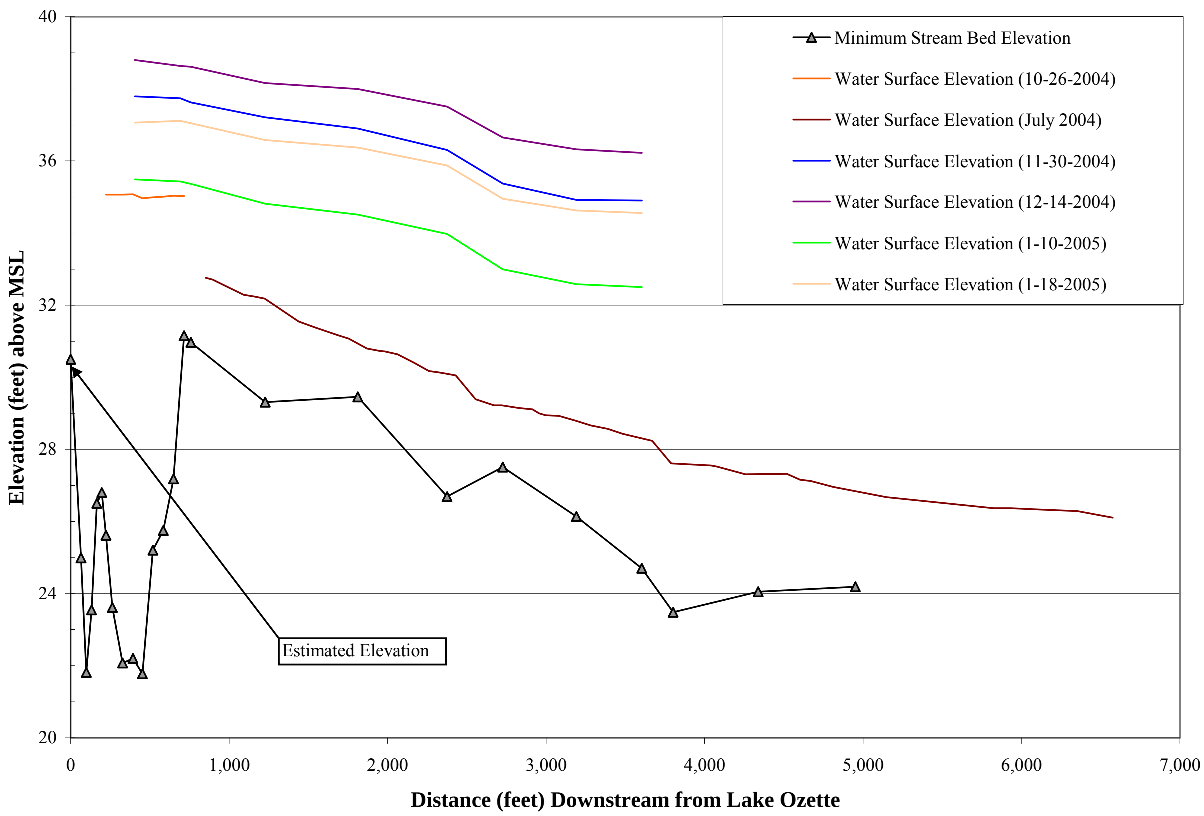

Figure 4.26. Longitudinal profile of Ozette River depicting both minimum stream bed elevation and water surface elevations at various lake stages (source: MFM, unpublished survey data; Herrera 2005).

The bankfull width of the Ozette River averages approximately 30 meters (98 ft) and depth varies by location and season. Shallow faster flowing reaches and slow, deep reaches intermingle throughout the river. Shallow reaches are typically <1 to a few feet deep during July-August flows. At many shallow riffles, several species of aquatic plants and two species of freshwater mussels, western river pearl mussel (*Margaritifera falcata*) and western floater mussel (*Anodonta kennerlyi*) are common. Upstream of logjams and at meander bends, the river becomes deep, often 2 to 3 meters (6.5-10 ft) during low summer flows (July through September). In these areas, submerged wood, boulders, and undercut banks provide important cover and holding areas for salmonids. Sculpin and crayfish reach large sizes and are common throughout much of the river. River otter (*Lutra canadensis*) sign is abundant along most of the river as well.

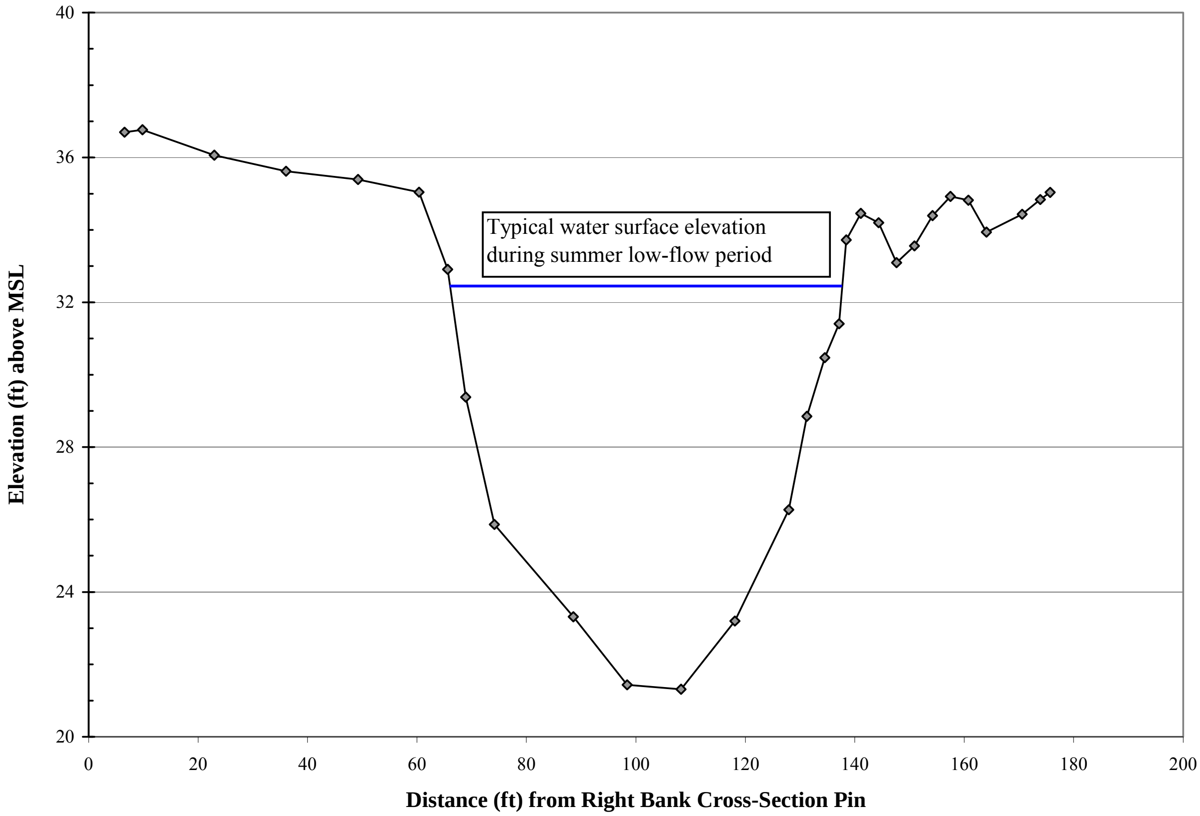

Figure 4.27. Ozette River channel cross-section mid-way between the ONP footbridge and the lake's outlet (source: MFM unpublished stream survey data). Note this cross-section is typical of the lake-to-river transition zone at the lake outlet, but not of the fluvial portions of the Ozette River.

4.3.1 Ozette River Floodplain Conditions

No formal analysis of floodplain conditions for the Ozette River has been conducted. There has been little if any floodplain disturbance in the past 50 years, although there is a record of disturbance prior to 1953. No roads parallel or cross the river. The river's entire length is now protected by either the ONP or the Makah Tribe's wilderness designation. The most significant floodplain impacts that have been identified for the Ozette River are associated with historical wood removal (see Sections 1.5; 1.5.3; 1.5.5).

The floodplain appears high and relatively narrow with steep banks for much of the length of the Ozette River. Kramer (1953) describes the area along both sides of the river (which may or may not be the floodplain) as "*marshy, covered with a thick growth of salal bushes.*" Currently, along much of its length the floodplain-channel margin is almost entirely vegetated with reed canary grass (*Phalaris arundinaceae*), believed to be introduced to the Pacific Northwest in the 1800s. Reed canary grass is generally considered to be a non-native invasive plant that colonizes disturbed areas, and it is likely that the grass has spread along the Ozette River since the 1950s.

4.3.2 Ozette River Riparian Conditions

Smith (2000) concluded that riparian conditions along the Ozette River were good. For the most part, riparian trees are at least several hundred years old, and they represent the characteristics of mature temperate rainforest. At the turn of the century, at least two homesteads were established along the Ozette River. In these areas, land was cleared, and the riparian area is characterized by younger trees, brushy areas, and less ground structure. The most degraded riparian conditions along the Ozette River occur near the lake's outlet. National Park Service infrastructure and maintenance of deforested areas along the upper quarter mile of the Ozette River have resulted in degraded riparian conditions along the right bank. Reed canary grass grows on gravel bars and exposed banks along much of the Ozette River below the bankfull width. The effects of this non-native grass on river processes have not been evaluated.

A cedar salvage operation in the lower river in the 1920s likely impacted the riparian zone locally. In 1952, riparian disturbance occurred in conjunction with wood removal from the Ozette River. However, even in 1952, it is likely that attempts were made to minimize damage to standing trees. Kramer (1953) reported that, "*All removal work was done by ground logging, as the National Park Service would allow no rigging of block or spar trees to be used in conjunction with jam removals.*"

4.3.3 Ozette River Pool and LWD Habitat Conditions

Pool and LWD habitat conditions are believed to be impaired from their historical conditions. Stream clearing occurred in the Ozette River, at least on a small scale, as early as the late 1800s. Photos of the upper Ozette River from the late 1800s to early 1900s show no evidence of large wood above the Nylund homestead, and one photo taken in the early 1900s shows cut logs in the river downstream of the ONP footbridge across Ozette River. Extensive LWD removal occurred in the Ozette River during the summer of 1952 (Kramer 1953; see Figure 1.13). Kramer (1953) reports that some of the logs removed from the Ozette River were 6 to 8 feet in diameter. Bortleson and Dion (1979) cite Patrick Bucknell (WDFW, oral communication, February 21, 1977) as stating that logjams were also removed from the Ozette River in 1956 and 1964. ONP and the Makah Tribe discussed removing wood from the river for fish passage as recently as 1982 (Blum 1982; Contor 1982), and conversations between some of the authors of this paper and local residents indicate that wood removal to pass small skiffs and canoes continued until about 1985.

LWD removal in the Ozette River is presumed to have significantly impacted habitat conditions within the river. Currently large stretches of the river are devoid of functional LWD. The low energy of the river suggests that LWD was not removed by floods, but only by deliberate human action. Pool frequency and refuge cover is low or nonexistent in these areas. The availability of pools that provide cover for holding fish is quite limited in some areas. LWD remnants from the removal projects, and the small amount of existing functional LWD, exemplify the habitat-forming qualities of LWD in the Ozette River. The majority of the large (>50 cm diameter) wood in the channel occurs as full-spanning logs with branches extending to or into the bed of the river (see Figure 4.28). These features are very efficient at capturing small pieces of organic debris such as branches, leaves, or other small pieces of wood. This results in excellent cover where effectively sized LWD accumulations remain. The full-spanning logs are also very efficient at creating associated under-scour pools that create pool tailouts that are important spawning habitat for some salmonids (e.g. Chinook). A small number of lateral scour pools are present in the Ozette River along bedrock faces, as well as two pools formed at confluences with minor tributaries that enter the river from the south. Virtually all of the habitat units that contain deep pools have large wood (often full spanning jams) as well. In the future decades to centuries, sizable conifer LWD would be expected to naturally recruit to the river.

While no detailed survey of wood and associated pool characteristics has taken place in the Ozette River, there is an obvious association between wood, pool frequency, and pool habitat complexity. Herrera (2005) conducted an LWD inventory of the upper 1 mile of the Ozette River during July 2004. They found a total of 17 LWD accumulations consisting of 1 or more pieces of LWD. However, within the upper half mile of the river all LWD accumulations (n=10) inventoried consisted of LWD <0.5 meters diameter and all but one piece was alder. All LWD obstructions in the upper 0.5 miles of the river were quite small and obstructed 10% or less of the BFW. In the lower 0.5 miles of the inventoried reach LWD key members in obstructions were much larger (3.7 times greater diameter on average) than those inventoried upstream. More than half of these jams obstructed 15-60% of the channel cross-section in the lower 0.5 miles.

Figure 4.28. Photo illustrating large trees spanning the Ozette River (photo looking upstream; source: MFM photo archive).

4.3.4 Ozette River Streambed-Substrate Conditions

Since the river receives no coarse sediment load from the lake, the low-energy bed is composed of a limited amount of glacially derived granites, and dominated by easily fractured/weakly cemented sedimentary rocks, which remain angular within the stream (this could also be the result of blasting to remove logjams). These sedimentary rocks apparently break down rather rapidly from the mechanical action of the stream and generate some silts and coarse sands as a result of this process. In many locations, freshwater mussels appear to be the dominant particle in riffles, particularly in the upper reaches of the river (Figure 4.29). Large amounts of fine, glacially derived sediments, input by Coal Creek during flood events, can be found initially near the upstream end of the Ozette River and then decreasing gradually downstream.

Herrera (2006) found that bulk sediment sample values were nearly identical in the Ozette River just upstream of Coal Creek (D_{50}=7.8mm) and in Coal Creek just upstream of the confluence with the Ozette River (D_{50}=10.1mm). No fine sediment sampling of spawning gravels has been conducted in the Ozette River. Kramer (1953) noted that "*Numerous gravel areas exist throughout the stream bed, being mainly in the upstream* *areas*." He further noted that "*Much of the stream bottom is covered with mud and silt*." Several contributing authors of this paper snorkeled the entire Ozette River during the summers of 2000, 2002, and/or 2004. The authors observed that river substrate varied by location along the river, but that spawnable gravel deposits appeared to contain moderate to high levels of fine sediment. The outlet of Lake Ozette as it transitions to the Ozette River is controlled by a shallow (~0.5 m)[12] vegetated bar of fine sediment, followed by a 3- to 4-meter (10-13 ft) deep pool with a cobble and boulder bed in the area of the ONP dock and boat launch, and a sand and gravel riffle just upstream of the confluence with Coal Creek (see Figure 4.26).

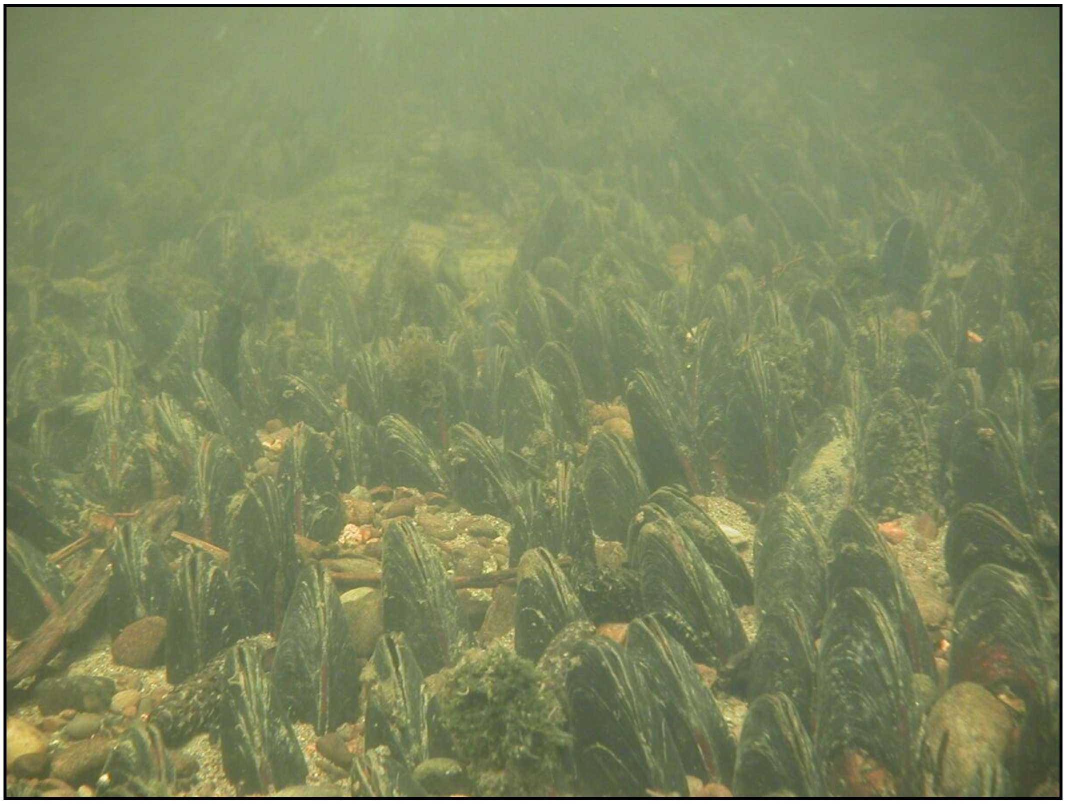

Figure 4.29. Typical Ozette River bottom conditions where freshwater mussel beds are present (source: Andy Ritchie).

Downstream of Coal Creek, the river bed is composed largely of gravel, pebble, sand, and silt. Much of this material is or has been derived from Coal Creek. Shallow, wide riffles and glides exist where wood is absent, and deep, sluggish pools and glides exist where wood is present and at the outside of many of the meander bends. Weak native siltstone outcrops in a few places along the upper river, and boulders, cobbles and gravel are locally present at these locations. Fine sediment (silt and sand) covers much of the bed of the Ozette River, since pools and sluggish glides dominate the river. However, low

[12] Depths in this section are reported relative to summer low flows corresponding to typical July and August discharge (Section 4.3.6), when data on these features have been collected.

flow riffles are composed of gravel and sometimes cobble, with varying levels of finer sand and silt mixed within the substrate interstices.

Fine sediment in potential spawning gravels appears relatively high for as least the upper 1/3 of the Ozette River, and not confined to the area immediately downstream from Coal Creek. Riffles along the lower 2/3 of the Ozette River appear to be coarser than upstream due to inputs from local bedrock outcrops and the relatively steeper gradient of riffles towards the mouth. However, fine sand and silt still dominate much of the bed area in the lower Ozette River.

4.3.5 Ozette River Water Quality

Water quality data for the Ozette River was first collected by Bortleson and Dion (1979) from 1976 through 1977. Unfortunately, the methods used are not clearly described and only graphical data are presented in the report. The most comprehensive water quality dataset is summarized by Meyer and Brenkman (2001). Meyer and Brenkman (2001) collected water temperature, dissolved oxygen, pH, specific conductivity, and turbidity data monthly from July 25, 1993 through November 30, 1994. Table 4.4 contains a summary of water quality sampling data for Ozette River reported by Meyer and Brenkman (2001). They concluded that other water quality variables in the Ozette River are not in the range that would prevent salmonids from migrating, spawning, or rearing in the river. Smith (2000) rated the water quality “poor” for Ozette River based on water temperature.

Table 4.4. Summary of water quality data collected in the Ozette River from July 21, 1993 through November 30, 1994 (source: Meyer and Brenkman 2001).

	Stream Temperature (°C)	**pH**	**Specific Conductivity (uS/cm)**	**Dissolved Oxygen (mg/l)**	**Turbidity (NTU)**
Minimum	6.7	6.4	31.3	8.1	0.4
Maximum	19.0	7.4	47.4	11.8	14.2
Mean	12.1	6.9	38.1	10.1	3.1
Number Months Sampled	n=21	n=15	n=20	n=17	n=15

In recent years additional water quality data have been collected from the Ozette River. MFM began collecting water quality data in February 2004. Data are typically collected monthly, but sampling frequency increases to approximately twice per month during the adult sockeye migration. Table 4.5 depicts a summary of the results of water quality sampling by MFM in the Ozette River. Water quality conditions measured by MFM are roughly within the range of conditions measured by Meyer and Brenkman (2001). The minor differences between data are likely a function of increased sample frequency during May, June, and July in the MFM dataset.

Table 4.5. Summary of water quality data collected in the Ozette River from January 15, 2004 through October 7, 2005 (source: MFM unpublished data).

	Stream Temperature (°C)	pH	Specific Conductivity (uS/cm)	Dissolved Oxygen (mg/l)	Turbidity (NTU)
Minimum	6.7	6.1	29.0	8.8	0
Maximum	20.76	7.6	48.5	16.0	5.7
Mean	13.62	6.8	40.5	11.22	<1
Number Months Sampled	n=29	n=29	n=29	n=29	n=29

Additional stream temperature data have been collected during seven summers from 1993 through 2005. Temperature data were collected at roughly the same location (near the confluence with Coal Creek) during all years with the exception of 1999 when data were collected near the confluence with the Pacific Ocean. Temperature data were collected on a total of 769 days between June 1st and September 30 (1993-2005). Maximum annual temperatures were recorded between July 22 (2002) and August 21 (1999; Table 4.6). Maximum temperature excluding 1999 data occurred between July 22 and August 9 (2004).

Table 4.6. Summary of maximum daily stream temperature observations from the Ozette River during temperature monitoring from 1993 through 2005 (source MFM unpublished data, Meyer and Brenkman 2001).

Year	Number of Days Sampled (6/1 to 9/30)	Date of Peak Temperature	Peak Temp (C)	Date of Peak 7-Day Moving Average Daily Maximum Temp.	Peak 7-Day Mov. Avg. Daily Max. Temp. (C)
1993	72	8/3/1993	22.2	8/8/1993	21.5
1994	108	8/5/1994	23.7	8/21/1994	23.2
1999	122	8/21/1999	19.8	8/25/99	19
2002	116	7/22 to 7/24/02;	22.4	7/28/02	21.9
2003	120	7/29/2003	23.8	8/14/2003	22.3
2004	114	8/9/2004	23.8	7/24/2004; 7/28/2004	23.0
2005	117	7/31/2005	22.6	8/05/2005	21.7

The 7-day moving average maximum daily temperatures observed from 1993 through 2005 are depicted in Figure 4.30. Figure 4.31 shows the number of days sampled and the number of days when water temperature exceeded 16, 18, and 20°C. Maximum daily stream temperatures exceeded 16°C on 736 days (95% of the days sampled) between June 1 and September 30 (1993-2005). Maximum daily stream temperature exceeded 18°C on 562 days (73% of the days sampled) and exceeded 20°C on 292 days (38% of the days sampled). When the 1999 data are excluded from the analysis, 16, 18, and >20°C were observed 98%, 81%, and 45% of the time respectively. The peak temperature measured during the 7 years of sampling was 23.8°C (recorded on 7/29/2003 and 8/9/2004). A temperature of 23.7°C degrees was also recorded on August 21, 1994. During the warmest period of summer, July 15 through August 15, data were collected on 218 days. Maximum daily stream temperatures exceeded 16°C on all days. Stream temperatures exceeded 18°C on 203 days (93% of the days sampled) and exceeded 20°C on 153 days (70% of the days sampled). The relatively high stream temperatures documented from 1993-2005 are thought to be primarily a function of natural conditions. Kemmerich (1945) reported that stream temperatures near the lake's outlet were between 19 and 21°C in late June 1926.

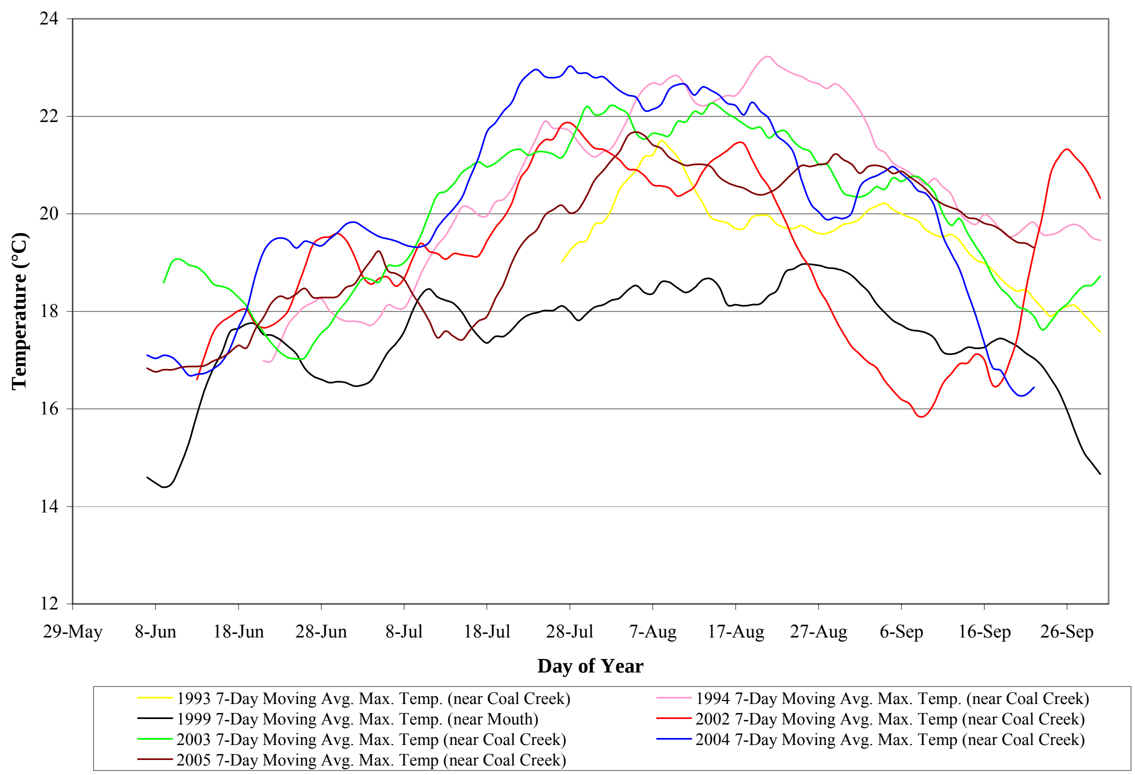

Figure 4.30. Ozette River 7-day moving average maximum stream temperature near Coal Creek from 1993-2005 (source: MFM unpublished stream temperature data; Meyer and Brenkman 2001).

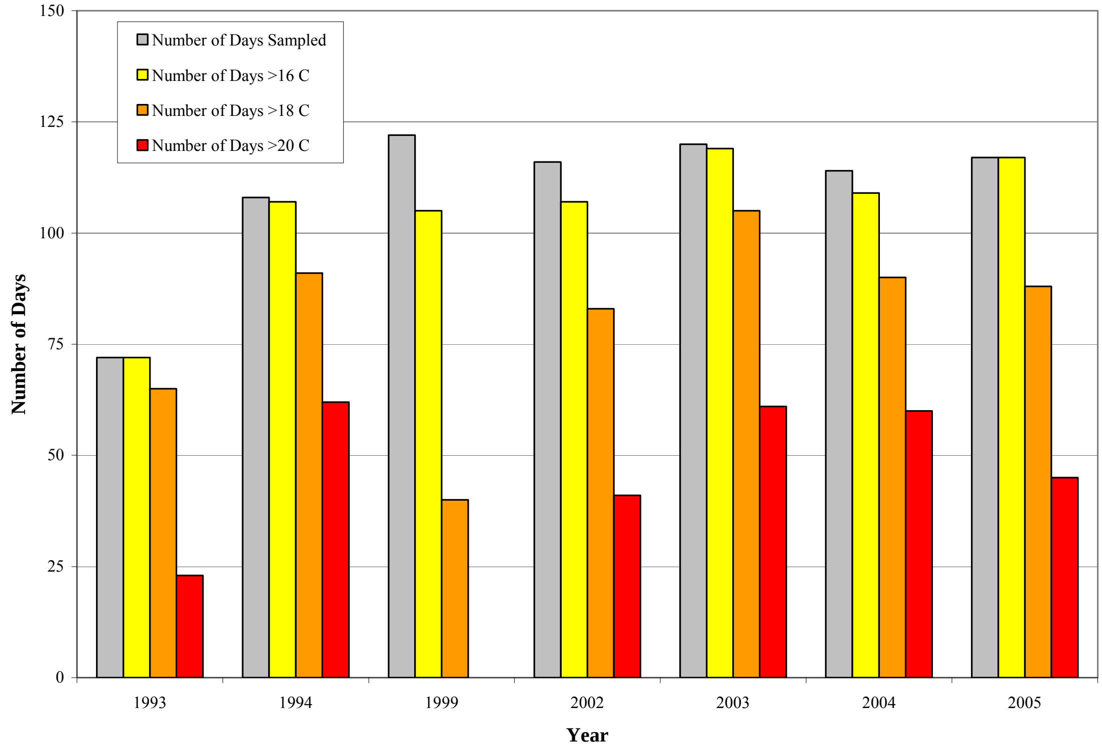

Figure 4.31. Number of days sampled and the number of days stream temperature exceeded 16, 18, and 20 °C in the Ozette River from 1993 through 2005 (source: MFM unpublished stream temperature data; Meyer and Brenkman 2001).

High water temperatures observed in the Ozette River appear to be a natural condition caused by solar heating of Lake Ozette surface waters (Meyer and Brenkman 2001). The extent to which watershed alterations have influenced Ozette River surface water temperatures has not been thoroughly studied, but based upon the lake summertime thermocline pattern (uniform temperatures in the upper 15 feet) it is unlikely that alterations affecting the lake outlet or the river depth could influence water temperatures in the vicinity that data were collected (i.e. upper Ozette River). Water temperatures observed near the river's confluence with the Pacific Ocean were generally lower than those observed upstream near the lake. In 1999, water temperatures near the mouth of the Ozette River never exceeded 20°C but did exceed 18°C on 40 separate days during the summer (MFM unpublished stream temperature data). However, 1999 was one of the cooler summers occurring during the past several years. Temperature data for Umbrella Creek collected during nine summers from 1993-2005 indicate that maximum stream temperature in 1999 was 2.6°C lower than the average annual peak temperature recorded during this period. Stream temperature data collected during the summer of 2005 showed little temperature moderation in the first 3.5 miles downstream from the lake during the sockeye migration period (Figure 4.32). This suggests that temperatures observed near the lake outlet are an excellent indicator of downstream temperatures and the overall temperatures experienced by migrating sockeye salmon.

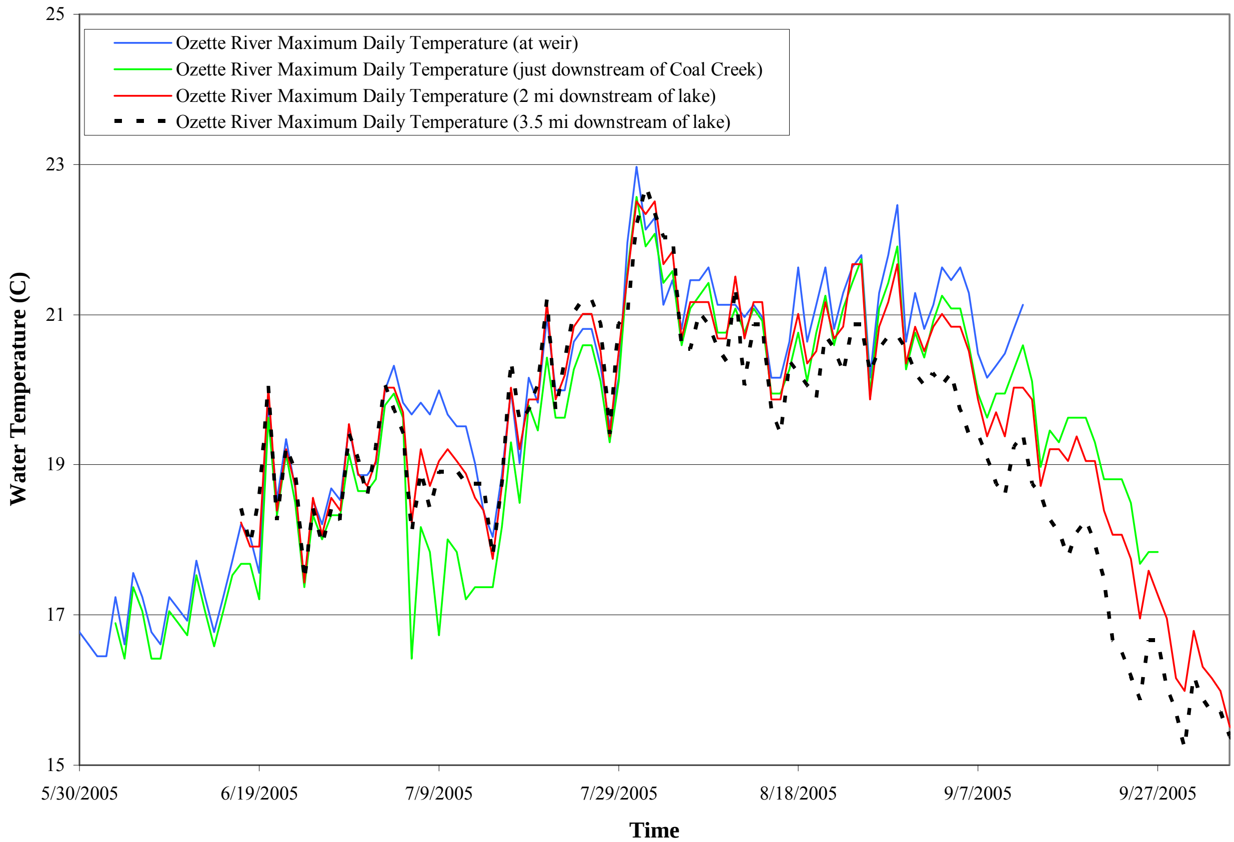

Figure 4.32. Ozette River daily maximum temperature at the Ozette counting weir, just downstream of Coal Creek, 2 miles downstream of lake, and 3.5 miles downstream of lake (source: MFM unpublished data).

In recent years Coal Creek has been observed to contribute sediment plumes to the Ozette River and Lake Ozette. From June 12 through June 14, 2000, approximately 3.7 inches (94 mm) of rainfall occurred while sockeye mark and recapture studies were being conducted in the Ozette River. Coal Creek was carrying excessive quantities of suspended sediment into the Ozette River; the water was extremely turbid, and flow reversal was observed where Coal Creek flowed up the Ozette River into the lake. Sockeye weir operators noted that several sockeye were observed covered in silt and some were observed bleeding from the gills. Several days after the storm, the river cleared and the entire river bottom in the vicinity of the weir and Coal Creek were covered in a mantle of silt and fine sand. A tour of the Coal Creek road network later that same summer revealed that much of the road network was contributing sediment to Coal Creek and its tributaries. Ditch erosion of up to 3 feet (1m) was observed along the mainline and many of the road ditches were connected to live streams. Water quality impacts to the Ozette River from Coal Creek sediment and turbidity have not been quantified, but observations suggest that they may be significant (see Section 4.4.4.5).

4.3.6 Ozette River Hydrology

The USGS made several miscellaneous measurements of instantaneous discharge in the watershed's streams in the 1960s and 1970s (Bortleson and Dion 1979), including the Ozette River and various tributaries to Lake Ozette. This started a series of four efforts to measure stream discharge in the Ozette watershed, with additional stream gaging by the USGS 1976-1979, by the ONP 1993-1994, and by the Makah Indian Tribe 2003-2005. All of the discharge measurements made in the Ozette Watershed between 1962 and 2005 are displayed in Figure 4.33.

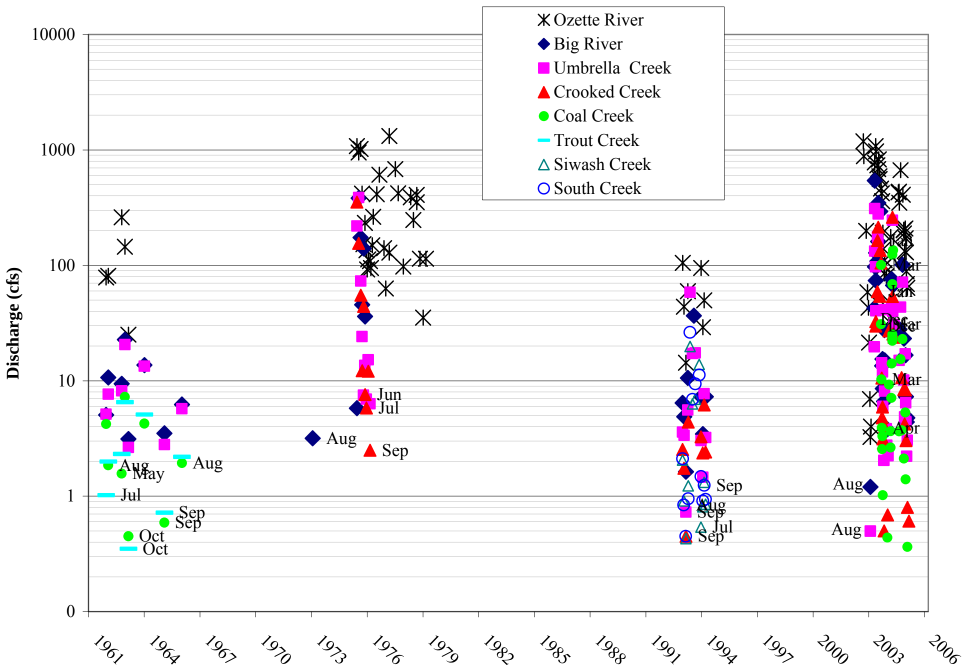

Figure 4.33. Instantaneous stream discharge measurements (source: USGS, Meyer and Brenkman 2001; MFM, unpublished discharge data).

While these data do not define the hydrologic regime of Ozette tributaries and Ozette River, they do help indicate the relative magnitude of discharges during different seasons, the water-producing abilities of each sub-watershed and Ozette River, and potential changes over time. The USGS maintained a continuous streamflow (discharge) gaging station at the outlet of Lake Ozette in the Ozette River from 8/1/1976 to 9/30/1979 (Figure 4.12) covering three complete Water Years (WY 1977, 1978, 1979). This station consisted of a continuous stage (stream level) recorder and periodic discharge measurements to develop a stage-discharge rating curve. This station was discontinued after water year 1979. The USGS has not collected additional hydrological data since this period.

In March 2002, Makah Fisheries Management installed a continuous stage gage at the same location as the historical USGS gage. This gage is located 30 feet above the footbridge and approximately 70 feet below the ONP manual stage plate (Figure 4.12). This gage automatically measures and records lake (or river) stage every 15 minutes.

Since early 2003, Makah Fisheries Management also has been measuring discharge (ft^3/s) at this location using current meters and wading rods at low to moderate flows, and current meters and bridgeboard cable equipment at high flows. These discharge data, along with continuous stage data, have been used to create a stage-discharge rating curve (correlation between stage and discharge; Figure 4.34).

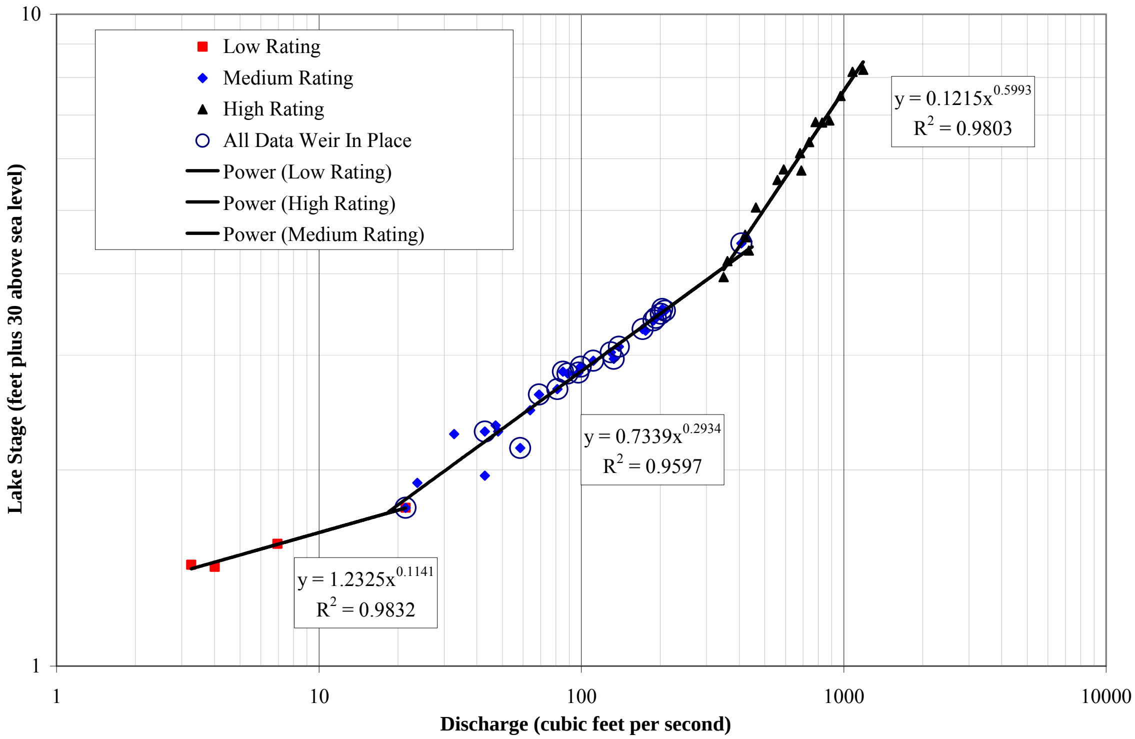

Figure 4.34. Ozette River rating curve developed by MFM (source: MFM unpublished data).

The Makah continuous stage recorder was installed using the same elevation datum used by both the previous USGS gage and ONP stage plate. The gage was installed with its zero elevation equal to a true elevation of 30 feet above mean sea level (MSL). The current correlation between the Makah gage and ONP stage plate is excellent (Figure 4.35). This close relationship is also assumed for the historical USGS gage recorder that was referenced to the same datum as the stage plate also used by the ONP.

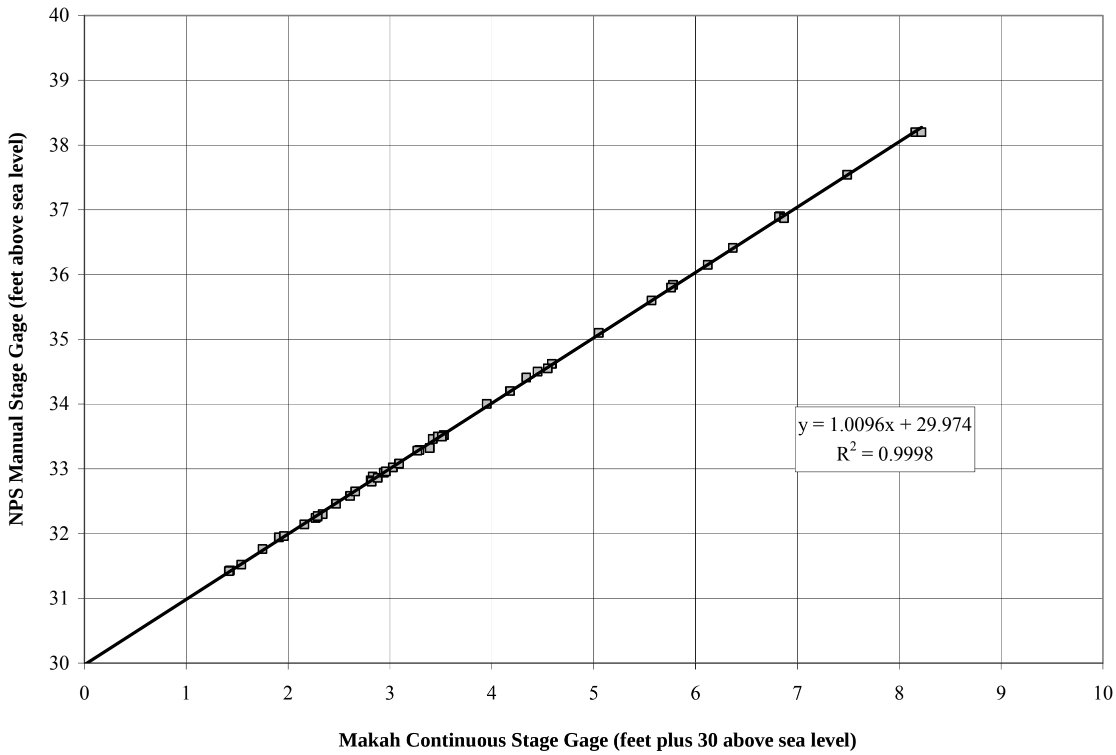

Figure 4.35. Correlation between MFM stage readings and ONP staff gage (source: MFM unpublished data; ONP unpublished data).

4.3.6.1 Lake and River Hydraulic Controls

Since the ONP did not collect discharge data along with its daily stage data, a complete discharge record does not exist to match the almost continuous stage record from 1976 to 2005. Ideally, if the channel configuration of the lake's outlet and Ozette River was constant, either the USGS or MFM stage-discharge rating curves could be used to estimate discharge from the 1981 to 2002 ONP stage data. At first this seems like a plausible assumption, since the locations of these stream gages are at the outlet of a very large lake that effectively traps all bedload and most suspended sediment, which is responsible for most channel morphology changes that might alter a rating curve. Furthermore, no obvious major trends are apparent in the historical ONP stage data that might indicate a changing elevation control on river/lake stage at this location. Indeed, the channel configuration in the immediate vicinity of these gages appears to be generally stable according to both local observations and historical artifacts (30- to 50-year-old bottles) found on the bed while snorkeling.

Shoreline erosion does occur along the lake margins on the north end of the lake. Deposition of longshore transported bar sediment in relatively small quantities has been observed near the outlet of the lake approximately 600 feet upstream of the ONP gage. This fine sediment is periodically colonized by vegetation, aiding further sedimentation, but is episodically flushed out by high lake levels via erosion of the low sill. However, both the ONP gage and MFM gage are located downstream of this minimally dynamic lake zone and appear to be relatively unaffected by any major sedimentation from upstream. The hydraulic control of the lake outlet into the Ozette River is not located at this upstream shoreline location or low sill, above the boat docks, launch ramp, and stream gages. The ultimate hydraulic control of the lake is located at the riffle downstream of the stream gages, just downstream of the bridge and just upstream of Coal Creek. This riffle is the highest bed or substrate elevation point before water spills into Ozette River (Figure 4.36).

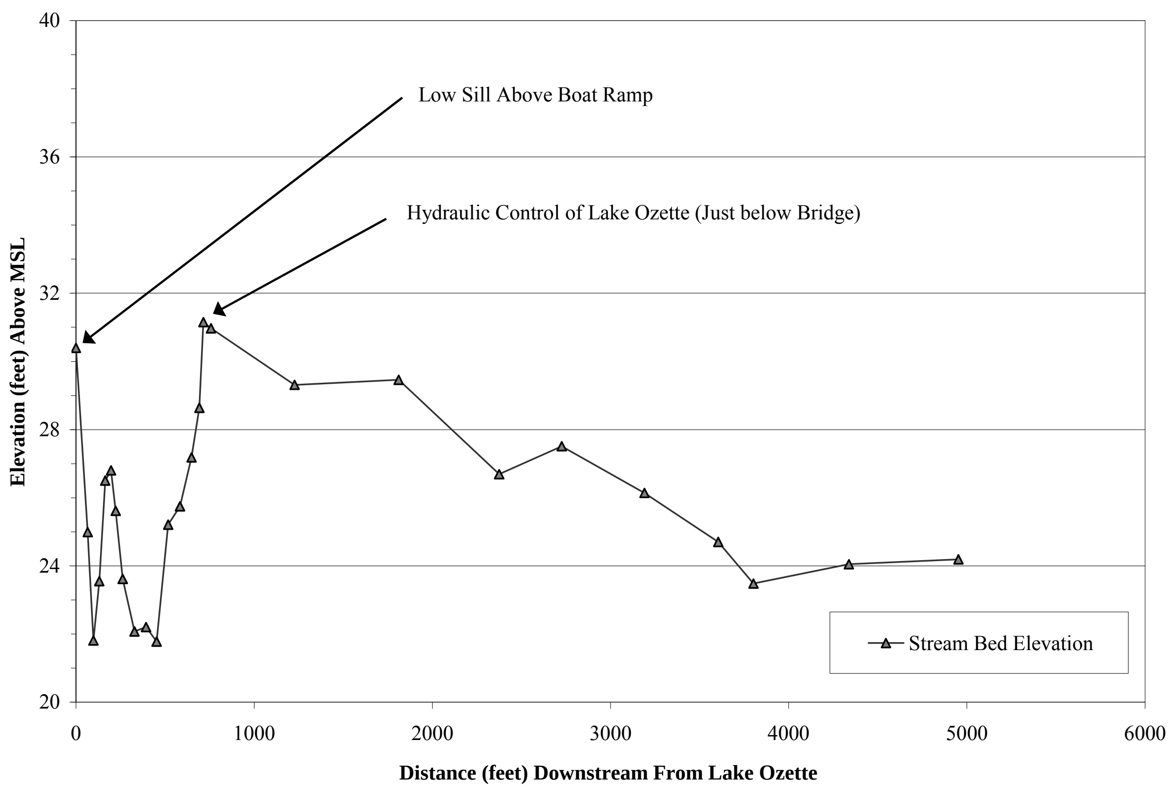

Figure 4.36. Longitudinal bed elevation profile of Ozette River depicting the hydraulic control point (source: MFM unpublished data; Herrera 2005).

This riffle controls lake outlet stage and river discharge at low to moderate flows. At higher flows, stage and discharge are regulated by the overall reach channel configuration, such as reach width, depth, slope, floodplain access, and roughness conditions. Channel roughness in the form of large woody debris (LWD) has been shown to have a significant influence on lake and river stage relative to discharge (PWA 2002; Herrera 2005). LWD in Ozette River has changed dramatically between 1953 and earlier to present (e.g., Kramer 1953). Over the last 30 years, LWD has been very slowly accumulating and recovering from past removal but is still assumed to be only a fraction of its historical abundance. Minor wood accumulations in the immediate vicinity of the stream gage and reach downstream of Coal Creek are fairly minor.

In order to quantify the potential changes in local riffle and channel hydraulic control at the lake outlet, the historical USGS stage-discharge rating curve was compared to the current MFM rating curve (Figure 4.37). In addition, stage and discharge data collected by the National Park Service in 1993 and 1994 are plotted in Figure 4.37. These data indicate that there are significant differences between the USGS and MFM ratings, as well as ONP data. At all stages, but especially at the lowest stages, the current MFM rating has shifted positively upward, approximately 0.4 to 1.0 feet between 1979 and 2003. The ONP data indicate that this positive shift occurred gradually, as the ONP data lie intermediate between the USGS and Makah data. This positive shift indicates that over the last 25 years, either: 1) significant channel aggradation has occurred, and/or 2) channel roughness has increased, thus affecting the hydraulic control(s) that regulate water release out of the lake. In other words, at the same discharge, the lake stage is higher in 2003 than in 1979. And conversely, at the same stage, the lake releases less water (discharge) into the Ozette River.

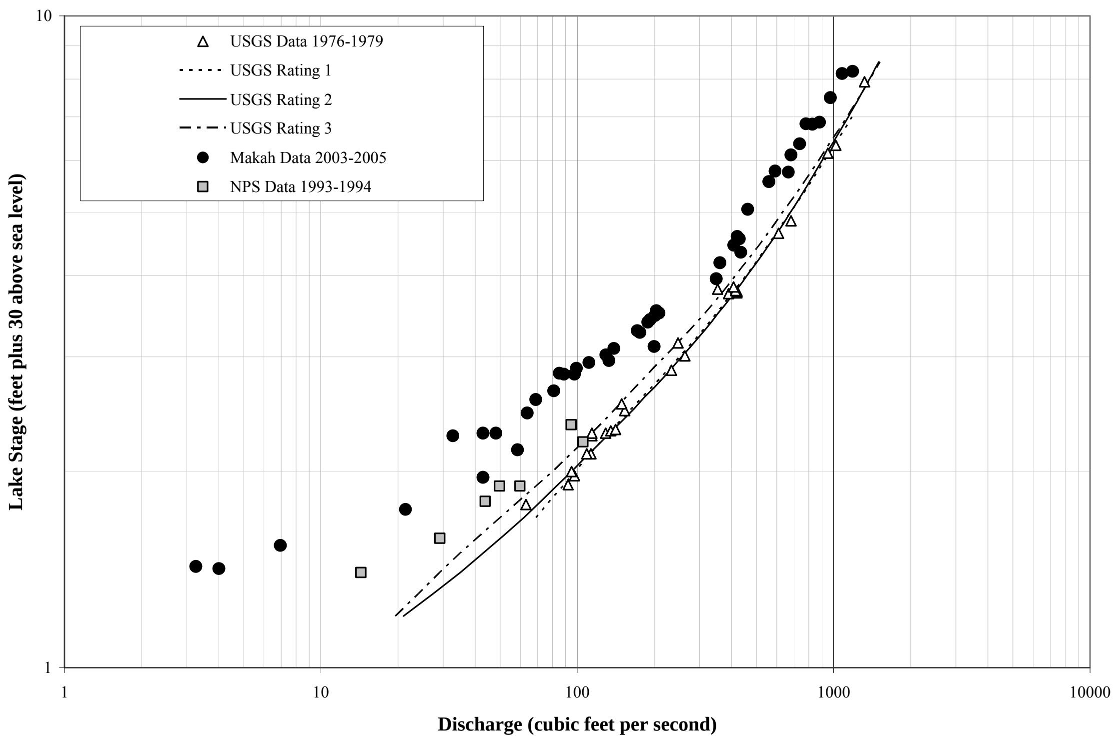

Figure 4.37. Comparison of USGS, ONP, and MFM stage-discharge relationships for the Ozette River.

In order to further quantify and document changes in hydraulic control at the lake outlet, cross-section data were extracted from both the USGS and MFM stream measurement notes. Since both gages used a common datum, the data were directly comparable. In addition, the current footbridge across Ozette River was constructed initially in 1974 and finished in summer of 1976, and has not changed in configuration to date, railings included (Dave Easton, NPS Personal Communication after review of construction drawings and photos). Thus, this bridge was the location of all medium and high discharge measurements by both the USGS and MFM, who both used portable bridge board and cable equipment to measure depth. Cross-section data were only extracted from measurements from the bridge, so that all measurements were along the same transect under the bridge. All USGS bridge measurements were taken from the upstream face of the bridge. Only some of the Makah measurements were taken on the upstream face, while most were taken on the downstream side. Therefore, some of the Makah measurements are located along the exact same transect as the USGS (upstream bridge railing; Figure 4.38), while others are taken eight (8) feet downstream on the downstream face (Figure 4.39). All depth (and thus elevation) measurements were accurate to the nearest 0.1 feet.

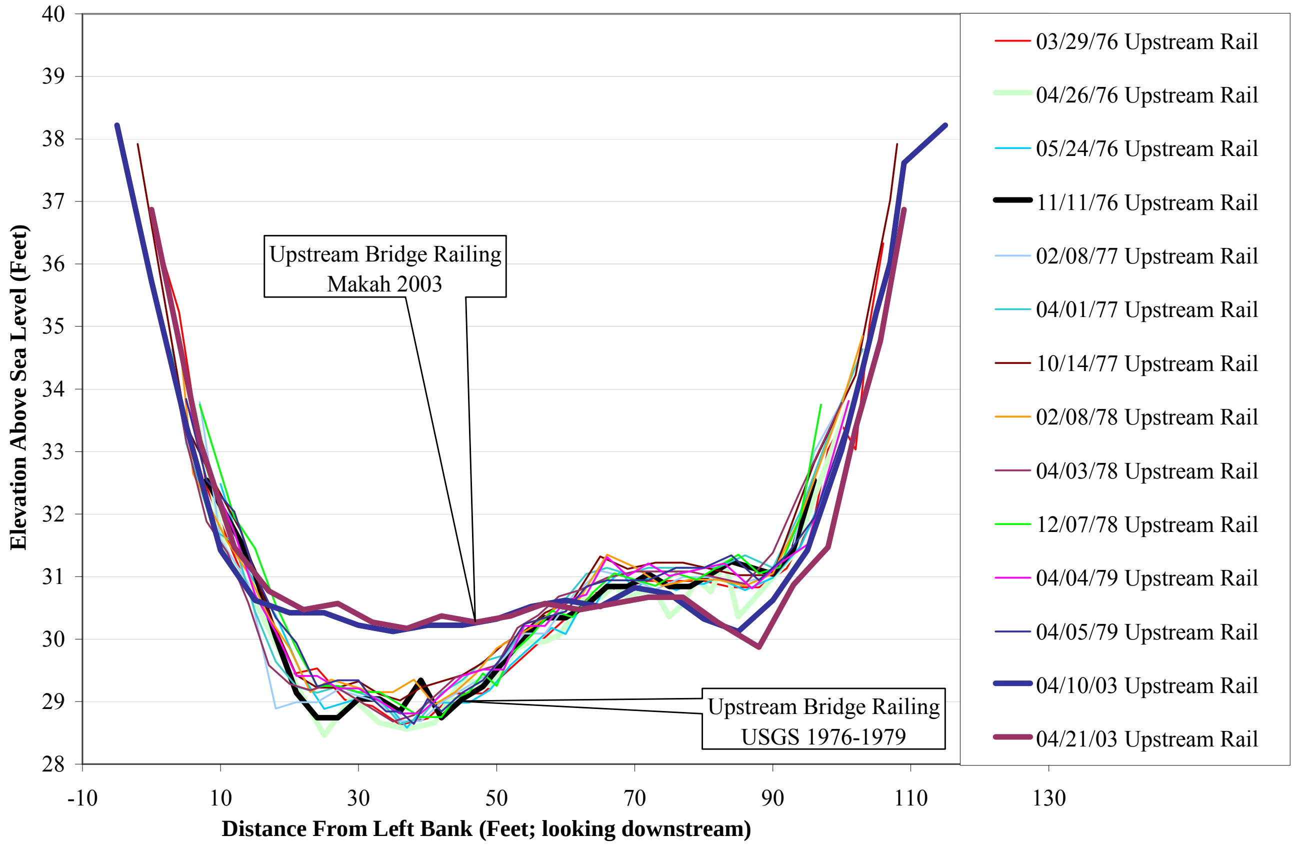

Figure 4.38. Cross-section elevation data collected from the upstream bridge railing on the Ozette River (source: USGS; MFM, unpublished data).

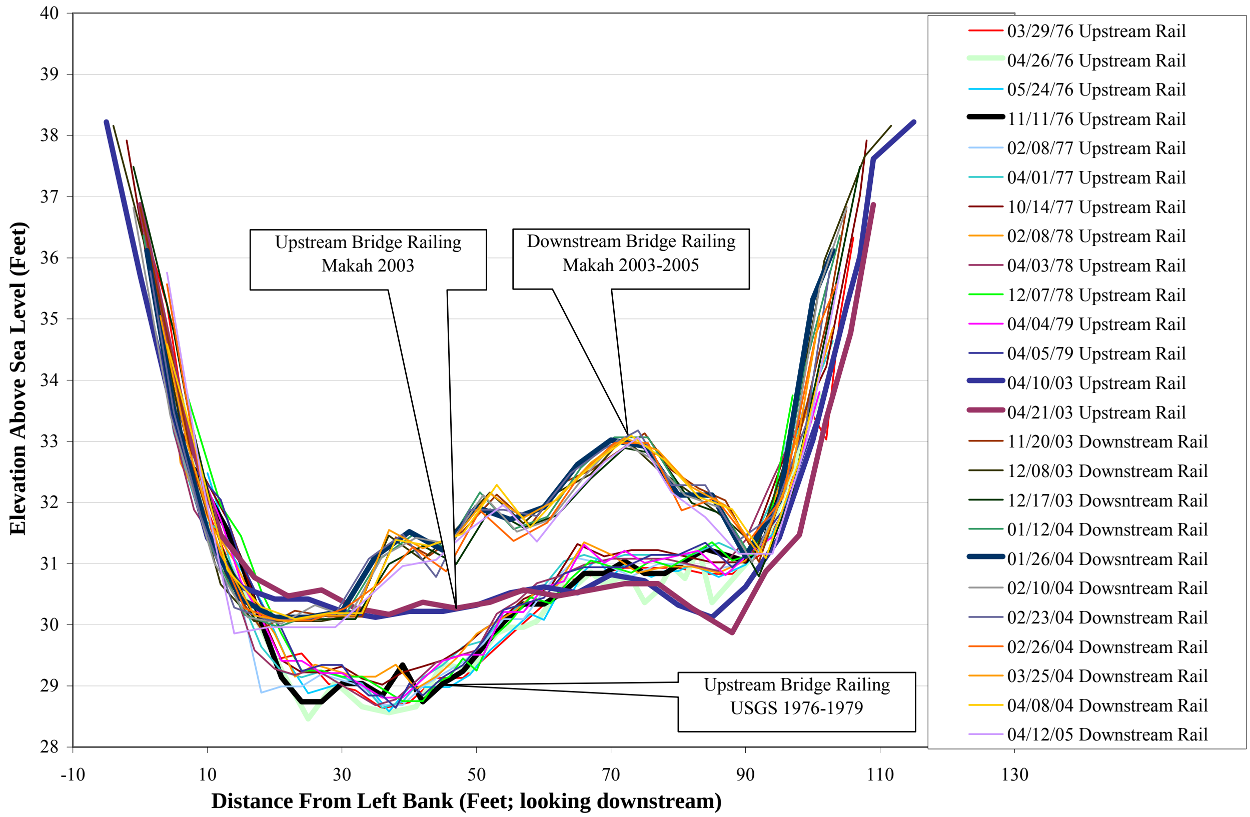

Figure 4.39. Cross-section elevation data collected from both the upstream and downstream bridge railings on the Ozette River (source: USGS; MFM, unpublished data).

The cross-sectional data displayed in Figure 4.38 and Figure 4.39 complement the stage-discharge and rating curve data. Between 1979 and 2003, the Ozette River channel thalweg (deepest point) under the bridge has aggraded approximately 1 vertical foot. This value also correlates to the average 1 foot upward shift in the rating curve between 1979 and 2003. Therefore, it is likely that sediment aggradation at the hydraulic control of the lake outlet is the dominant factor altering the river and lake stage/discharge relationship over the last 25 years.

Local observations at the bridge location and hydraulic control provide additional qualitative data that sedimentation has occurred at the controlling riffle. USGS water year summary description (WY 1976-1979) and measurement notes describe the controlling riffle downstream of the bridge as a "*cobble [and gravel] riffle about 100 feet downstream of gage.*" "*Channel control is probable at extremely high stages*" (USGS, unpublished discharge measurement notes 1976-1979). Currently the riffle contains very few cobble particles and is dominated by sand and small gravel. Particle size in the riffle is nearly the exact same size as the substrate size in Coal Creek (Herrera 2006). In addition, a mid-channel bar has developed just downstream of the bridge. Looking downstream from the bridge, significant deposition is observable in the middle of the channel and especially along the right bank. This right bank sediment deposit is formed in the eddy that develops upstream of the confluence of Coal Creek, and is readily observable in Figure 4.39 as an increase in bed elevation along the right bank progressing from the cross-sections upstream of the bridge to downstream.

Coal Creek in its present channel location (compared to its historical distributary channels) undoubtedly has a periodic influence on the stage-discharge relationship at the stream gage and hydraulic control just upstream of the confluence. This hydraulic influence consists of both 1) sediment deposition at the Ozette River confluence and 2) backwater effects of Coal Creek stage or discharge on the stage and flow dynamics of Ozette River upstream of the confluence, through the bridge opening and over the hydraulic control. This backwater effect occurs when the relative stage (or discharge) in Coal Creek is equal or greater than the stage (or discharge) upstream in the Ozette River. This backwater effect was first noted on October 14, 1977 in the USGS discharge measurement notes and has been periodically observed by NPS and MFM personnel since then. During most of the time or duration of most discharge situations, Coal Creek has a minimal to negligible backwater influence on Ozette River. Indeed, over six water years of stream gaging and 66 discharge measurements, this influence has not been quantified with current meters, but only visually observed.

The typical observed situation of backwater influence occurs when Lake Ozette and Ozette River are relatively low, typically below 34 or 35 feet, which can be the case during late spring, summer, or early fall. While not common, intense precipitation events can occur during these seasons, which can cause Coal Creek to quickly rise to flood stage after several inches of rain. Due to the low relative stage of Lake Ozette during these situations, response to these "dry season" events is minimal due to the large storage capacity of Lake Ozette. Thus, the relative stage of Coal Creek is temporarily elevated above Lake Ozette and Ozette River, overwhelming the stage-discharge patterns of Ozette River. Typically, during these events Coal Creek rises and falls quickly due to a lack of sustained multi-day precipitation (Figure 4.40). During these events, local observers have witnessed a variety of changes in hydraulic flow conditions, including 1) backwater without reverse flow in Ozette River, 2) backwater with partial reverse flow (east bank) through the bridge span (Figure 4.41), and 3) full reverse flow through the bridge cross-section into Lake Ozette.

During an event, the hydraulic conditions and flow directions become readily apparent because of the relatively high suspended sediment yields of Coal Creek compared to clear water exiting the lake. However, it is often the case that while sediment plumes and velocities are observed to move upstream, the Ozette River stream gage does not register extreme anomalous stage (and thus discharge) readings, even though Ozette discharge estimates (via the rating curve) through the bridge cross-section during these short Coal Creek spikes (less than one day rise to fall) are obviously incorrect, especially during the highest part of the Coal Creek flood wave. However, as compared to lake stage data at Tivoli Island, Ozette River Stage data does show a slightly elevated stage during high Coal Creek discharge events when Lake Ozette stage is relatively low (Figure 4.40).

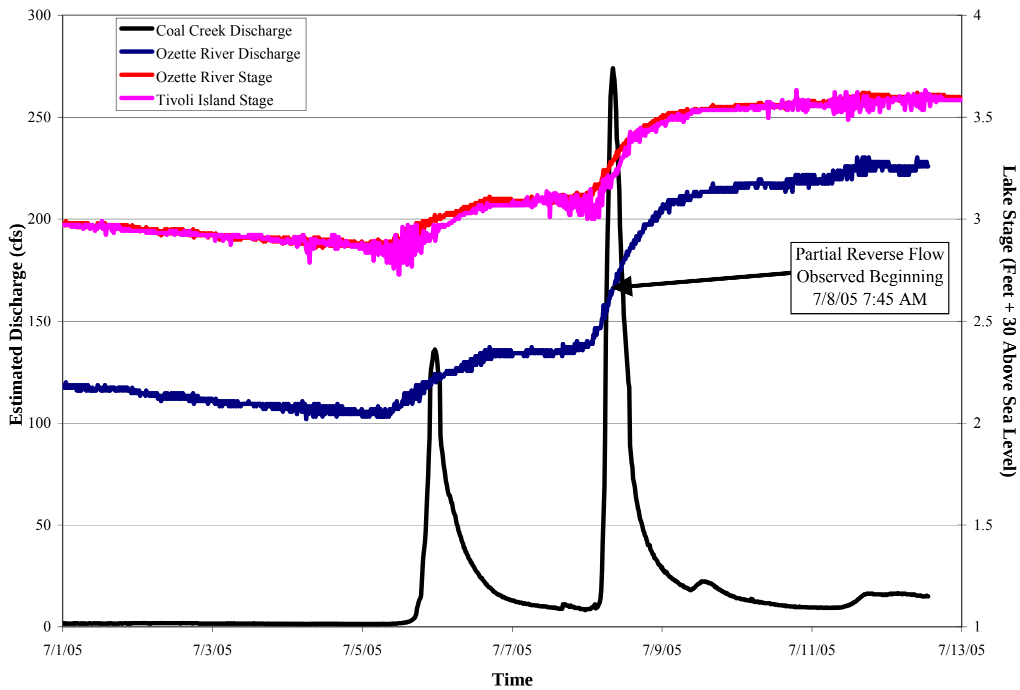

Figure 4.40. Comparison of discharge and stage of Coal Creek, Ozette River, and Lake Ozette during partial flow reversal at Ozette River stream gage (source: MFM unpublished data).

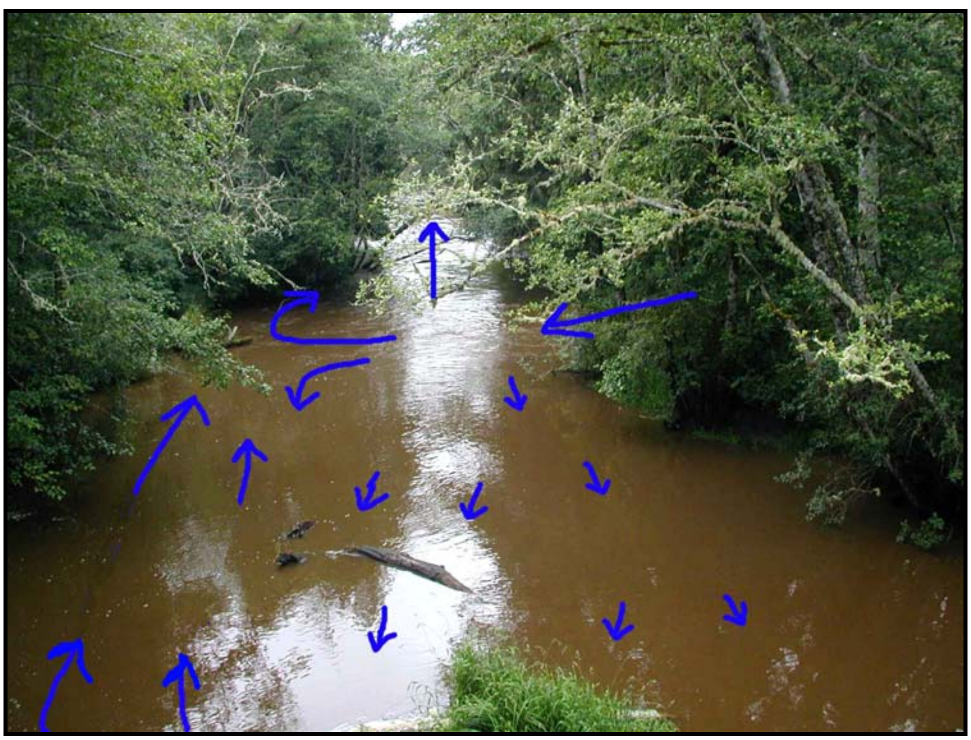

Figure 4.41. Photo depicting partial flow reversal of the Ozette River on July 8, 2005, blue arrows represent approximate velocity vectors (source: MFM).

Sediment deposition at and upstream of the mouth of Coal Creek is most pronounced during these backwater conditions. At moderate to high lake stages when Ozette River and Coal Creek discharges are moderate to high, Ozette River dominates the flow pattern at the confluence and quickly pushes Coal Creek discharge and sediment loads downstream, forming an abrupt right turn of the sediment plume at the confluence. This situation limits the ability of Coal Creek sediment to migrate upstream. However, this situation reverses during high Coal Creek and low Ozette River discharges. During these conditions, sediment first begins to migrate upstream along the east (right) bank of Ozette River via the large hydraulic eddy that forms following the displacement of Ozette River flow patterns toward the opposite west (left) bank (Figure 4.41). During large anomalies, sediment and velocities can reverse upstream across the entire river cross-section. These observations match the quantified aggradation patterns at the Ozette/Coal confluence (Figure 4.38 and Figure 4.39), where bar growth over the last 25 years has been concentrated toward the east (right) bank of Ozette River.

As a final influence on the Lake Ozette stage and Ozette River discharge relationship, MFM operates a seasonal salmon counting weir at the outlet of the lake. This weir is installed and removed seasonally from approximately April 15 to August 15. It is installed just below the footbridge across Ozette River, above Coal Creek, 30 feet below the Makah stage gage, and 100 feet below the NPS stage gage. The porous weir consists of one-inch circular metal tubes placed approximately ½ inch apart, so as to alter upstream salmon migration and force fish to migrate through a viewing chamber. In addition, on some years *Vexar* mesh is place across the face of the weir to increase smolt trapping efficiency while smolt trapping operations are underway (April-May). The weir and trapping operations have varying backwater effect on Lake Ozette, depending largely on the amount of leaf litter buildup on the face of the weir. Maximum backwater observed at the weir (upstream versus downstream stage), is 0.3 feet, but is typically less. Lake stages during weir operation typically range from 32 to 35 feet. At the lower end of the rating curve near 32 feet, considerable scatter exists in the rating data depending on whether the weir is in place or not (see Figure 4.34). More discharge data are needed below a stage of 32.5 feet to better define the stage discharge relationship and exact effect of the weir on this relationship.

4.3.6.2 Measured and Reconstructed Ozette River Discharge

Following the analysis of the Ozette River rating curves and changes in the hydraulic control over the last 25 years, it became clear that the assumption of a stable rating curve over time was incorrect. The date(s) of these rating shifts are unknown; however, NPS discharge data from 1993 and 1994 suggest that the change was gradual. Therefore, it becomes impossible to accurately transform all the NPS stage data between 1981 and 2003 into discharge data and reconstruct a mostly full period of record for discharge between 1976 and 2005. However, a more generalized approach was used that brackets the two rating curve extremes, assuming that the actual rating curve between 1981 and 2003 was between (above) the USGS curve in 1979 and (below) the Makah curve in 2004 (see Figure 4.37). Using both the USGS and Makah rating curves, this approach provides the potential range of discharges (maximum and minimum) between 1981 and 2002, using the NPS stage data. These hydrographs are shown in Figure 4.42, and display a more detailed picture of the hydrology as compared to the extremely short USGS and Makah records. NPS discharge data in 1993 and 1994 confirm that during the mid-1990s, discharge was less than predicted by the USGS rating curve, but greater than the Makah rating curves (Figure 4.37 and Figure 4.42).

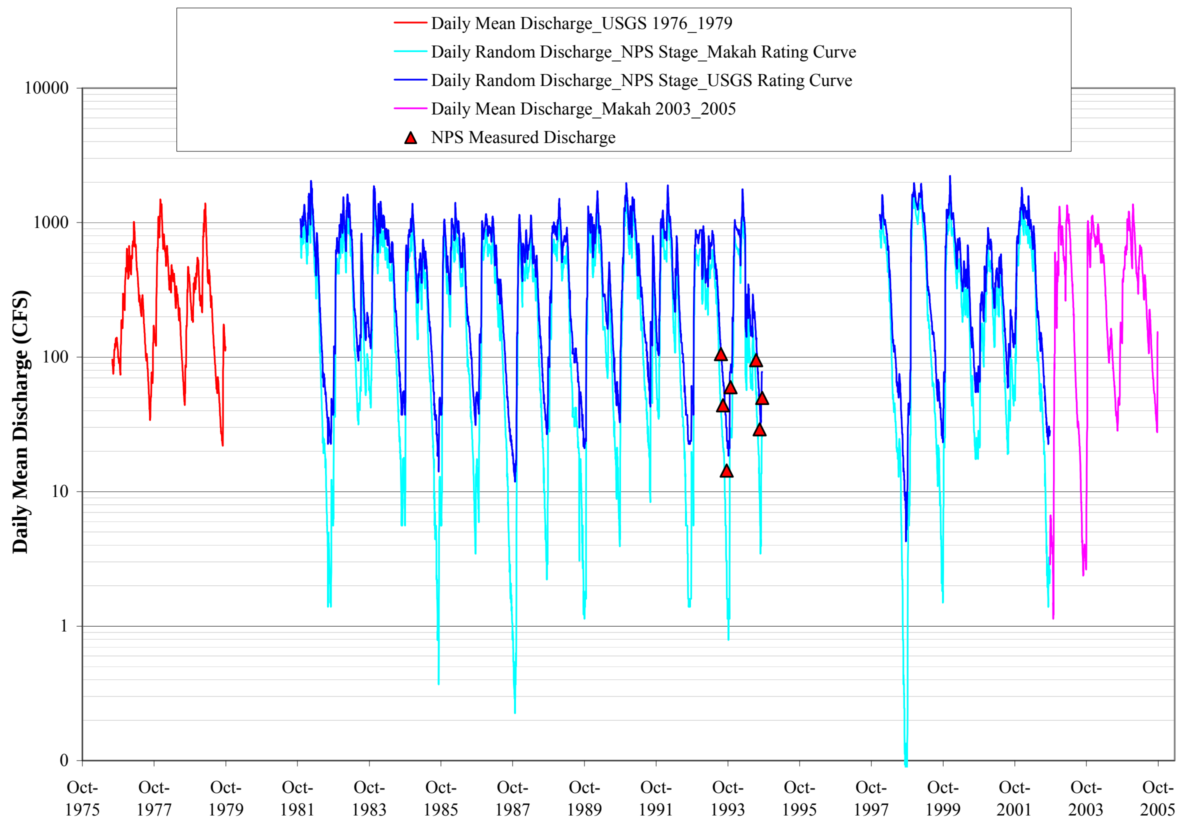

Figure 4.42. Reconstructed Ozette River discharge contrasted by estimates produced by USGS and MFM rating curves.

While this bracketed dataset is not robust enough for detailed analyses, several significant observations and trends can be gleaned from the dataset. Two datasets were created using the two different rating curves that represent the two extreme (maximum and minimum) discharge scenarios. The first dataset consists of measured USGS discharge data (1976-1979), NPS stage data and the 1979 USGS rating curve (1981-2002), and measured MFM discharge data (2003-2005). The second dataset consists of measured USGS discharge data (1976- 1979), NPS stage data and the 2004 MFM rating curve (1981-2002), and measured MFM discharge data (2003-2005). Both datasets use the 1993 low flow discharge measured by the NPS. Annual maximum (peak flow) and minimum (low flow) extremes were extracted from these two datasets. Each dataset for the period of record was plotted to detect potential trends in high or low flow discharge over time (Figure 4.43 and Figure 4.44).

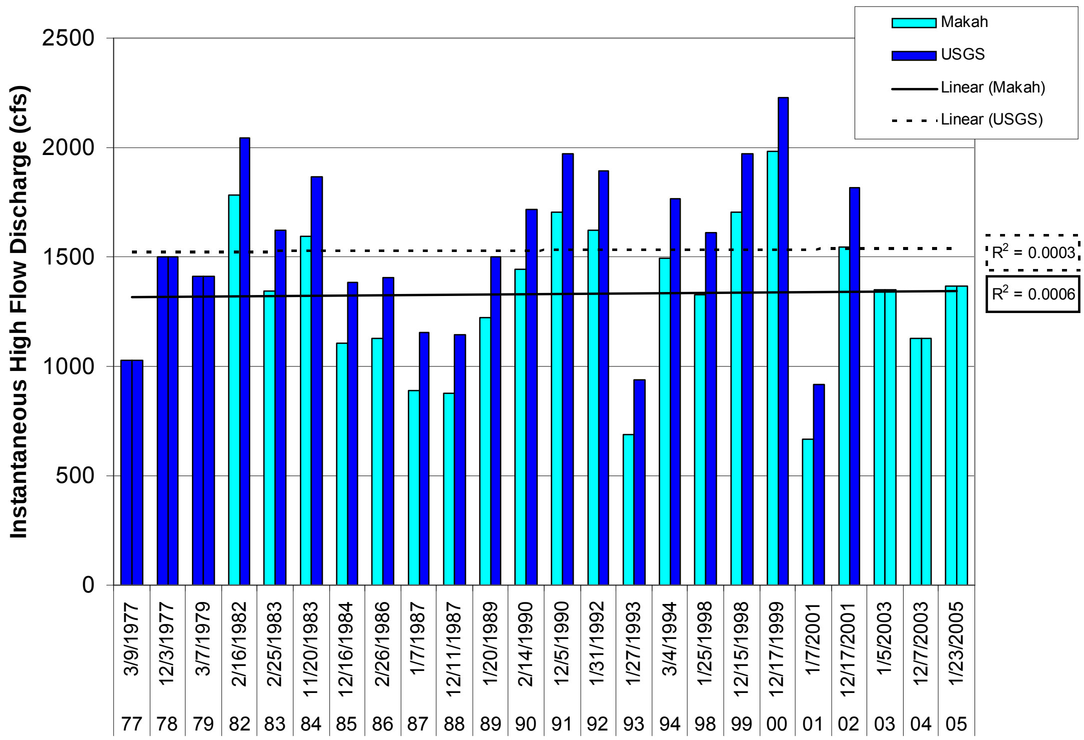

Figure 4.43. Ozette River bracketed annual peak flow discharges for water years 1977 through 2005 (source: USGS, ONP, and MFM stage data).

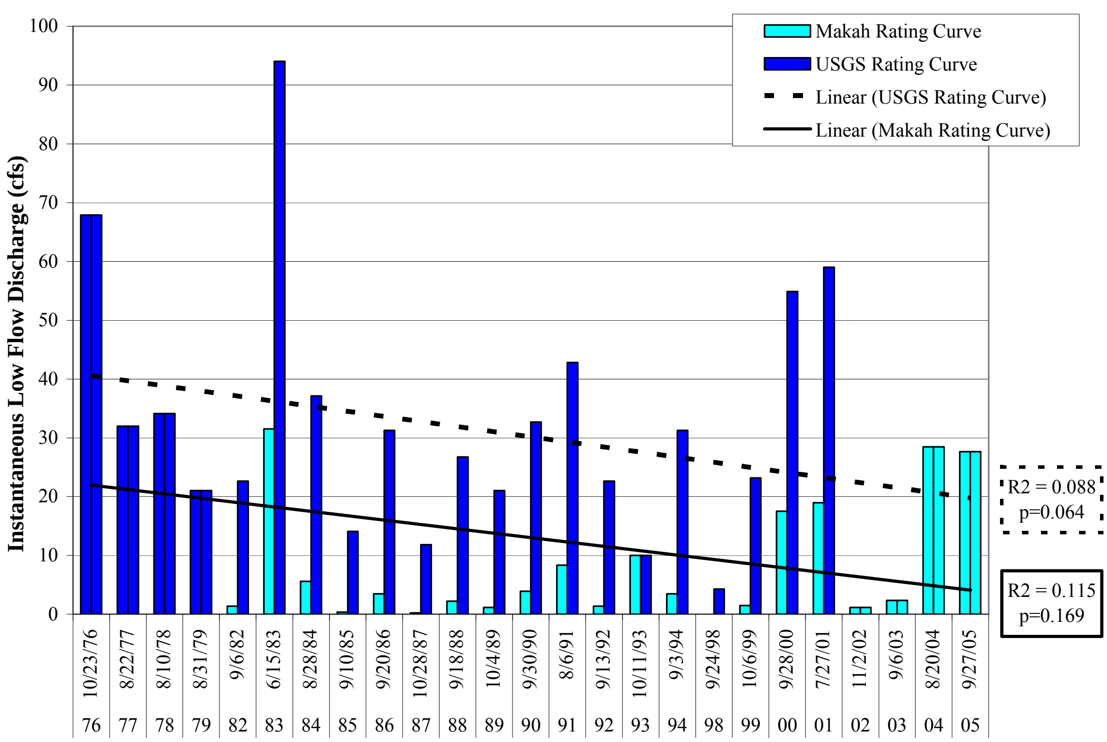

Figure 4.44. Ozette River bracketed annual low flow discharges for water years 1977 through 2005 (source: USGS, ONP, and MFM stage data).

Using either the USGS or MFM rating curves, no obvious trends were observed over time for peak flow discharges (Figure 4.43). Annual peak discharges range from a minimum potential low of 666 cfs (WY01, drought winter) to a maximum potential high of 2,229 cfs (WY 00, a wet winter). For annual low flow discharges, weakly significant decreasing trends exist for both data sets (Figure 4.44). Probability values were calculated using the non-parametric, rank-based, Mann-Kendall test (Kendall's tau) (Helsel and Hirsch 2002).

The extreme nature of the low flow hydrology at the Ozette River was not known until summer 2003. Before then, the USGS from 1976-1979 indicated fairly high sustained base flows in the river as compared to other regional rain-fed rivers. However, after the reinstallation of a gaging station in 2002 and better examination of the climate and precipitation records at Quillayute and NPS stage data, it appeared that winter and summer precipitation during the USGS record was average or above average and did not fully represent the range of variability of low lake stages and river discharges. While the extreme minimum discharge values calculated using the NPS stage data and Makah rating curve Figure 4.42) are likely not accurate (i.e. it is unlikely that the river went almost dry in 1985, 1987, and 1998), subsequent measured discharges indicate that the Ozette River can regularly drop below 20 cfs in the summer, and periodically get down to 1 to 4 cfs during extremely dry summers. Measured summer discharge data (June-November) for both the USGS (1976-1979) and Makah (2002-2005) data sets are graphed in Figure 4.45, along with the total summer precipitation (inches July-Sept) at the Quillayute Airport. These discharge and rainfall data indicate how average or above average the USGS data years were compared to the more extreme dry years during 2002 and 2003 measured by Makah.

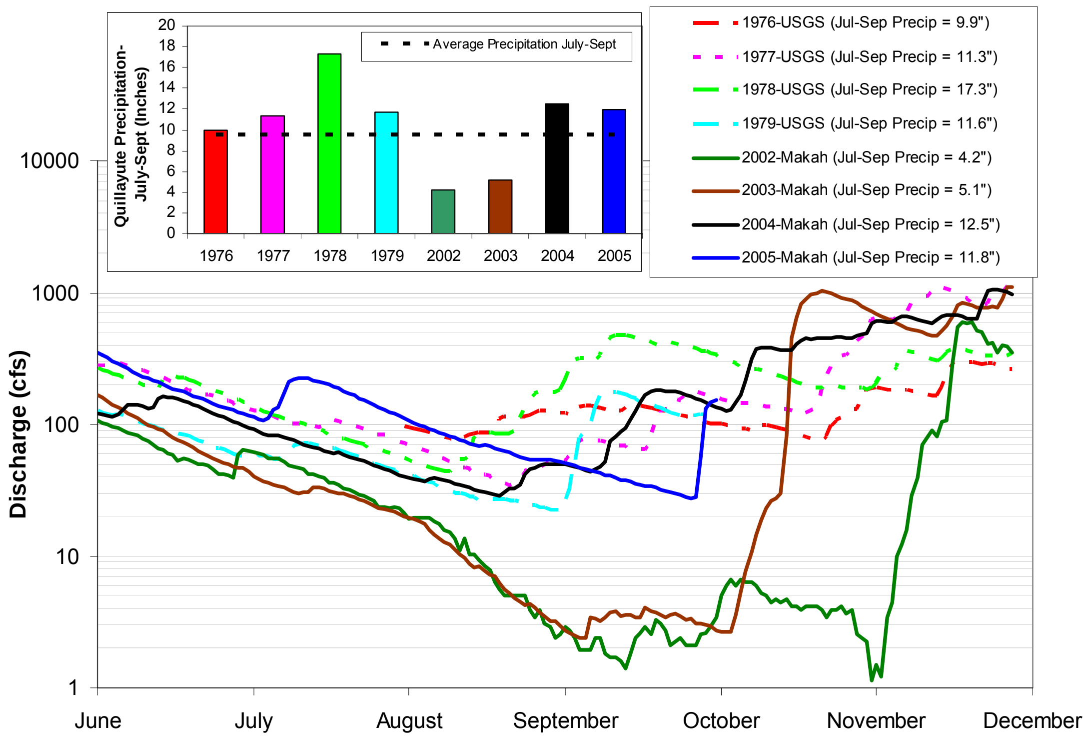

Figure 4.45. Ozette River discharge, summers 1976-1979 and 2002-2005 (source: USGS and MFM streamflow data).

During the summers of 2002 and 2003, discharge in the Ozette River above Coal Creek dropped to between 1 and 4 cfs of flowing water on the surface of the channel (Figure 4.45). For example, during summer 2003, measured discharge ranged from 58.4 cfs on 7/2/03, 42.9 cfs on 7/21/03, 21.4 cfs on 8/1/03, 7.0 cfs on 8/19/03, 3.3 cfs on 8/28/03, and 4.0 cfs on 9/7/03 after one inch of rain on 9/6/03. The dry season summer rainfall, lake stage and river discharge levels during the summers of 2002 and 2003 do not appear to be rare or uncommon events. Dry season summer rainfall, lake stage, and presumably river discharge were also comparably low during the summers of 1967, 1982, 1985, 1992, 1996, and 1998 (Figure 1.4; Figure 4.13). It is unknown whether the dry summer periods of 2002 and 2003 are just part of the overall hydro-climatic variability of the Lake Ozette watershed, or are partially influenced by trends in climate change (IPCC 2001) and the global trend of the hottest years on record recently (2000 to 2005), or whether anthropogenic land use has partially influenced the water balance of the Ozette Watershed and Ozette River.

Of particular local interest is the potential effect of sedimentation at the mouth of Coal Creek on the release of water from Lake Ozette. Due to the raise of the hydraulic control of Lake Ozette over the last 25 years (Figure 4.35), lake storage between 29 and 30 feet above MSL may be unavailable for release into Ozette River. However, the nature and extent of low flow changes in the Ozette River is still poorly understood and is likely a result of multiple factors acting cumulatively. Hyporheic flow [or shallow subsurface flow (e.g., Harvey and Bencala 1993; White 1993; Boulton et al. 1998; Edwards 1998; Bencala 2000)] through the recently deposited sediments above Coal Creek may mask the surface expression of water release from the lake. An unknown portion of the total outflow of water from Lake Ozette may be contained in hyporheic flow. Undoubtedly, hyporheic flow was still a component of the lake's outflow in the late 1970s and before, but the percentage of hyporheic flow to total flow may have changed over time due to sedimentation.

Only two sets of measurements shed light on the potential significance of hyporheic flow through the outlet of Lake Ozette into Ozette River. On August 28, 2003 at 11:00 a.m., the discharge of Ozette River above Coal Creek was measured at 3.26 cfs on the surface. The discharge was measured to be 4.65 cfs approximately 200 feet below Coal Creek on the same day at 12:30 p.m., showing a relative increase of 1.39 cfs potentially the result either of hyporheic flow through the bar upstream of Coal Creek, or the Coal Creek contribution. Surface flow of Coal Creek at this time was likely under 0.5 cfs. However, the accuracy of these low flow discharge measurements is approximately 8%, indicating a potential maximum increase of discharge below Coal Creek of 2.02 cfs and minimum increase of 0.75 cfs. If the surface flow of Coal Creek was less than 0.5 cfs, then the hyporheic contribution to Ozette River flow below Coal Creek was between 0.25 and 1.5 cfs. On September 28, 2005 at 9:45 a.m., the Ozette River above Coal Creek was measured at 23.72 cfs, while on the same day at 10:15 a.m. the Ozette River below Coal Creek was measured at 24.49 cfs. At the same time (9/28/05 9:00) the Coal Creek stream gage upstream calculated Coal Creek discharge as 0.41 cfs. The remaining flow would indicate 0.37 cfs of hyporheic flow through the bar upstream of Coal Creek. However, this difference is within the potential 8% error of the discharge measurements. Better quantification of the nature of hyporheic flow through the outlet of Lake Ozette could be fairly easily conducted using standard techniques (Bencala et al. 1983; Harvey et al. 1996; Harvey and Wagner 2000; Packman and Bencala 2000) or by more detailed longitudinal measurements of surface discharge along the upper end of Ozette River to document and quantify the extent of losing and gaining reaches.

4.3.6.3 Synthesized Ozette River Hydrographs

Due to the significant changes in the stage/discharge rating curve at the lake outlet between the 1979 and 2003, the NPS stage data could not be precisely and accurately transformed into discharge data, leaving an uncompleted discharge record for Ozette River. To compensate for this lack of data, discharge data for Ozette River have been synthesized from data in adjacent watersheds. As part of water resource investigations for the Water Resource Inventory Area (WRIA) 20 Watershed Planning Process, the U.S. Bureau of Reclamation (USBOR) gathered all available stage and discharge data for synthetic data construction (see Lieb and Perry 2004 for additional detail). Due to the high variability and poor correlation of instantaneous discharge between Ozette River and adjacent rivers (a partial result of the high water storage effect of Lake Ozette at the daily time step), all discharge data were summed into monthly total streamflow volumes (acre-feet per month or average cubic feet per second, per month). Regression equations were developed between monthly total streamflow for the Ozette River and monthly total streamflow at nearby gages including Hoko River (USGS 12043300), Sooes River

(USGS 12043163), and Dickey River (12043100). The measured Ozette River data (i.e., USGS and Makah data) were used to calibrate application of the equations. Data were synthesized for two locations on Ozette River for the period 1962 and 1999: Ozette River below Coal Creek and Ozette River at ocean mouth.

These synthesized data only represent monthly averaged flows (cubic feet per second), but are very useful for defining both the general flow regime (hydrograph magnitude, duration, timing) and variability over time (1962 to 1999). These data are displayed in Figure 4.46 and Figure 4.47, as annually dispersed flow duration probabilities (% of time average flow is less than [<] a given discharge). Note that at any given point in time, the instantaneous discharge could be much higher or lower than the average monthly flow. These data are not useful for defining extreme instantaneous discharges such as extreme low summer flows or peak flows. As another note of caution, several sources of data for the Ozette River were not available to the USBOR at the time of their synthesis calculations, resulting in several omissions or errors in their results. For example, the USBOR did not have the USGS and Makah data that indicate a significant rating shift (sediment aggradation) at the Lake outlet above Coal Creek. Thus, their calculations did not take into account changes in outlet conditions over time that would control water release from the lake. These changes include changes in large woody debris roughness following removal in 1953 and slow recovery over time (PWA 2002; Herrera 2005). Lastly, they made an incorrect assumption regarding where the USGS measured discharge during the period 1976 to 1979. The USGS made discharge measurements upstream of Coal Creek at the footbridge, similar to Makah data. Perceived changes in discharge out of Lake Ozette between 1979 and 2003 were partially a result of sediment aggradation and a rating shift, not changes in discharge measurement location.

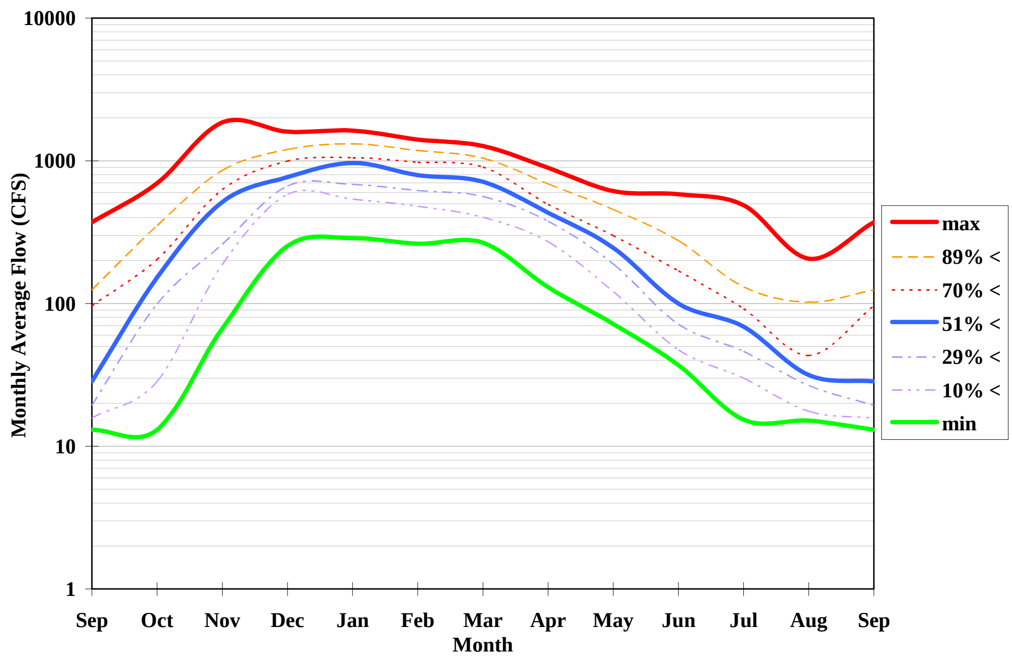

Figure 4.46. Ozette River below Coal Creek, annually (1962-1999) dispersed flow duration curve (source: data synthesized by USBOR).

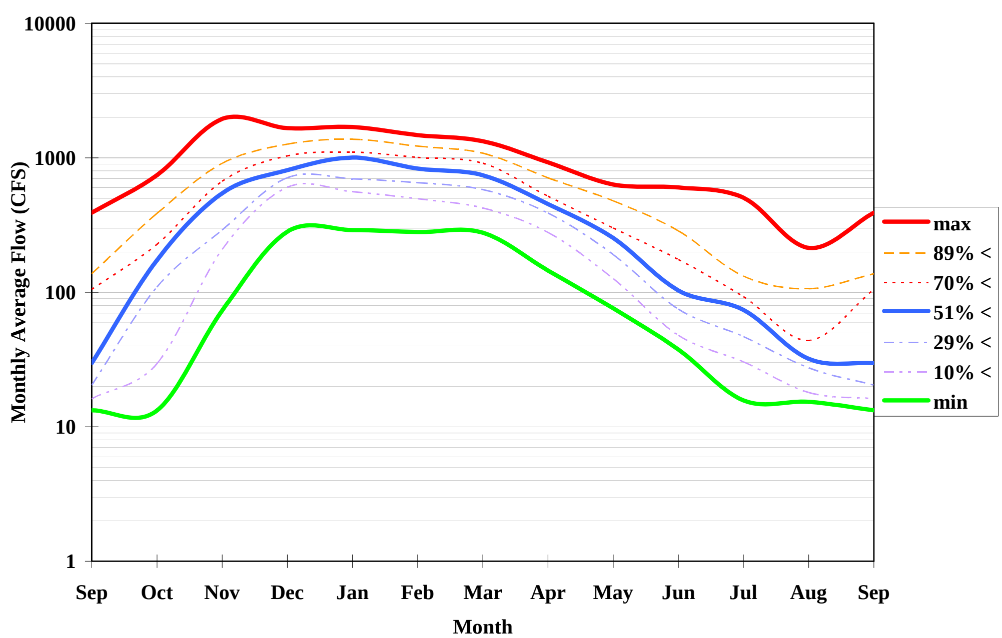

Figure 4.47. Ozette River at confluence with Pacific Ocean, annually (1962-1999) dispersed flow duration curve (source: data synthesized by USBOR).